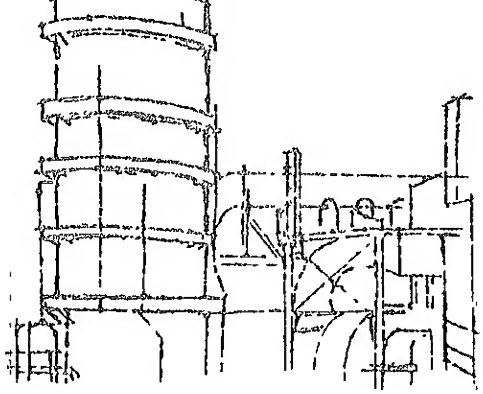
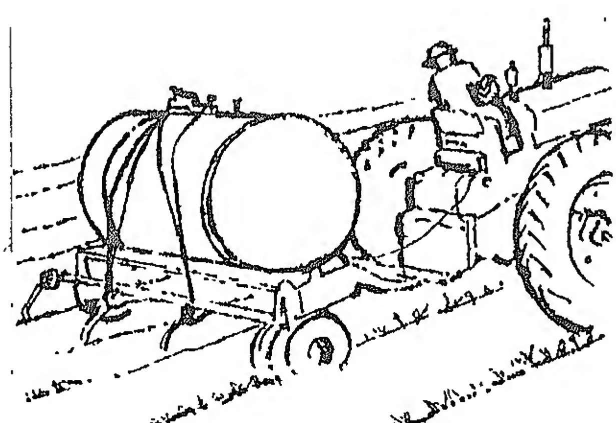


RESOURCE ADJUSTMENT in the FERTILIZER INDUSTRY

with emphasis on Michigan



Economic Research Service
U.S. Department of Agriculture
In Cooperation with
Michigan State University

ABSTRACT

As one of a series of reports from a comprehensive study of the U. S. fertilizer industry, this publication examines the supply of fertilizer in Michigan. Areas covered include: (1) the organization of the industry that minimizes the cost of producing, distributing, and applying fertilizer in the short and long run; (2) the least-cost transition to the long-run organization; (3) the impact of changes in the nutrient ratio; (4) the cost associated with use of suboptimal products; (5) the impact of abatement activities of coal-burning electric power generating plants on the industry; and (6) the economic relationship between wet and furnace phosphoric acid.

Variables included (1) products--over 30, with approximately 200 formulations; (2) functions, including production, storage, handling, transportation, processing, sales, and application; (3) location, including the Gulf Coast, Florida, Saskatchewan, the Midwest, and Central Michigan, plus local facilities throughout Michigan; (4) size; (5) technical processes; and (6) nine transportation modes.

Keywords: Minimal cost, Fertilizers, Nitrogen, Phosphate, Potash, Sulfur, Production, Distribution, Application, Location, Simulation, Fertilizer industry.

PREFACE

One in a series that presents results of a study of the fertilizer industry, this report focuses on the supply of fertilizer in Michigan. Though the treatment of problems in the industry is neither exhaustive nor conclusive, the information provided illustrates what can be done both in researching an industry and in suggesting improvements in fertilizer production and distribution. This material should be useful to producers of nitrogen, phosphate, and potash; carriers; bulk blenders; ammoniator-granulators; liquid mixers; retailers; farmers; and the sulfur and power industries.

Two earlier reports, listed below, were devoted to the model and the data.

1. The Model. The power of a linear programing model used as a simulation tool is substantial. Although some characteristics of linear programing make handling certain aspects of industry activities difficult, this tool was helpful both in identifying what can be achieved in the fertilizer industry and in evaluating alternatives. Although large amounts of resources are required to develop and use the model, the benefits can be extraordinary. A complete disucssion of the model is presented in:

Bell, David M., Dennis R. Henderson, and George R. Perkins. A Simulation of the Fertilizer Industry in the United States: With Special Emphasis on Fertilizer Distribution in Michigan. Mich. State Univ., Agr. Econ. Rpt. No. 189, East Lansing, Feb. 1972.

2. The Data. A large effort was made in compiling and verifying the data used in the study. Not only are the data a strength of the model, but they may also be used by other researchers and firms in their own studies. The data are discussed and presented in:

Henderson, Dennis R., George R. Perkins, and David M. Bell. Simulating the Fertilizer Industry: Data. Mich. State Univ., Agr. Econ. Rpt. No. 190, East Lansing, Feb. 1972.

Joint support was provided by the Department of Agricultural Economics, Michigan State University; and the Marketing Economics Division (MED), Economic Research Service (ERS), U. S. Department of Agriculture (USDA).

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HIGHLIGHTS

The cost of meeting demand for fertilizer in Michigan could be reduced about 25 percent in the short run and nearly 33 percent in the long run, as determined from a linear programing model that focused on production and distribution of fertilizer consumed in Michigan. Savings would be distributed between fertilizer firms and farmers.

The transition from current industry organization to longrun least-cost organization could be achieved fairly simply. After making shortrun adjustments, the industry would replace facilities as they wore out with facilities needed in the longrun setup.

Of the few products needed in the long run, anhydrous ammonia would be used for direct application, and monoammonium phosphate and granular potassium chloride would be blended to supply P_2O_5 and K_2O in the desired ratio. The ammonia could be produced at lesser cost in the fertilizer consuming area than in other areas from which the product would have to be transported. To minimize costs in the long run, monoammonium phosphate, the least-cost source of P_2O_5, should be produced near the phosphate mines.

Use of bulk blenders represents a significant method of lowering fertilizer cost but larger blenders are needed and must also be operated more efficiently than is currently true in Michigan.

As a high-cost source of nutrients, liquid mixed fertilizer cannot compete economically (handling costs included). However, because its handling characteristics give this type a noneconomic advantage, limited use may continue in the future. A reasonably good source of low-cost nutrients is found in granulated mixed fertilizer. Though granulated mixes cost more than bulk blends, they are less expensive than liquid mixes and suspensions. Nonetheless, their use will probably decline because they have neither the efficiency of bulk blends nor the handling advantages of liquid mixes.

Farmers represent the primary force in reorganizing the fertilizer industry. They have not always selected low-cost nutrient products because of preference, insufficient information, and other factors. By continuing to purchase high-cost products, they can block industry efforts to improve performance. Or, farmers can stimulate the transition to better performance by buying the low-cost products. This alternative would mean a substantial change in their purchase patterns.

Current retail operations for dry, liquid, and ammonia fertilizers are high-cost activities. Alternative distribution channels would be preferable economically.

Recovery of ammonium sulfate from abatement activities of coal-burning electric powerplants will not affect the fertilizer industry significantly in the longrun least-cost organization. Recovery of sulfur from fuels will have a major impact on the sulfur industry for some time, however. Though the effect on sulfur uses in the South will be limited, the impact on Northern sulfur markets, where manufacturing is concentrated, could be substantial.

More effective controls on sulfur oxide emissions are forthcoming; thus, many coal-burning powerplants will have to adjust their operations. If the fertilizer industry adjusts to the longrun minimal cost organization, power firms will find it advantageous to produce byproduct sulfuric acid and market it in industrial areas.

RESOURCE ADJUSTMENT IN THE FERTILIZER INDUSTRY: WITH EMPHASIS ON MICHIGAN

by
David M. Bell, David L. Armstrong,
George R. Perkins, and Dennis R. Henderson

INTRODUCTION

Few other industries have changed as dramatically over the past 30 years as the fertilizer industry. Between 1940 and 1970, U.S. consumption of nitrogen (N) increased over 17-fold, while consumption of phosphates (P_2O_5) rose five-fold and potash (K_2O), nine-fold (10, p. 12; and 26, p. 8). 1/ The structure of the industry has changed as well. For example, just prior to World War II, only seven firms were manufacturing anhydrous ammonia in the United States, and the four largest accounted for 95 percent of all production. By 1969, their number had increased to more than 85, with the four largest firms accounting for less than 18 percent of all production (7, pp. 28-29; and 10, pp. 28-33).

The part of the industry that deals directly with farm customers has also changed significantly. For example, the number of bulk blend plants in the United States increased from 201 in 1959 to 5,158 in 1970, and the number of liquid plants rose from 335 in 1959 to more than 2,751 in 1970 (11).

Throughout the late 1950's and 1960's, the industry strained to keep pace with rapidly increasing consumption. But in the mid to late sixties, the anticipated rise in consumption failed to materialize; by 1968, the capabilities of the industry to produce and distribute its products far exceeded actual consumption. In 1970, the estimated manufacturing capability of commercial fertilizer companies in North America was 61 percent greater than estimated domestic consumption (22, p. 1).

This overcapacity and the corresponding low prices made other problems surface in the industry that previously had been masked by high returns enjoyed by industry firms. Perhaps the most basic difficulty has been the lack of full understanding of the complex interrelationships between the many aspects of the industry. This situation has prevented decisionmakers from making adjustments toward improved economic performance.

Objectives

This study was undertaken to investigate the economic environment in which firms operate in the Michigan fertilizer industry. It was designed to complement the planning and decisionmaking processes of individual firms by tracing out the interrelationships between the numerous firms (including manufacturing, distributing, transporting, and so on) and business practices in the industry and by determining the industrywide consequences of changes in these practices.

Three general areas of interest to industrial leaders were investigated. Because of the myriad of products, processes, locations, and other options, it was difficult

1/ Underscored numbers in parentheses refer to items in References at the end of this report.

to determine the sets of industry organization that would lower costs of supplying the three basic nutrients. Therefore, as the first area of interest, short- and long-run optimal organizations of the industry were determined, analyzed, and compared with the existing industrial situation. 2/ Implementation of the most efficient transition from current industry organization to the longrun optimal organization was also examined. Since this transition is sensitive to several economic forces, the analyses were conducted under alternative sets of economic and industrial conditions.

Second, the interrelationships between fertilizer supply and demand were investigated. In the absence of concise delineation of these interrelationships, it was difficult to determine what types of facilities should be used to supply fertilizer to farmers. It is not clear from industrial practices whether or in what way consumption patterns should be altered to best utilize industry capability. Questions considered involved the alternatives and associated costs and returns. The interrelationships between, and the type of, desirable adjustments in fertilizer consumption patterns and the organization of the supplying industry were other important questions. The costs associated with suboptimal behavior--that is, the use of products that do not result in lowest costs--in the Michigan fertilizer market were also analyzed.

Third, the effect of byproducts on the fertilizer industry was examined, especially those from pollution abatement activities in coal-burning electric power generating plants. Several processes have been developed for recovering sulfur oxides from powerplant smokestacks. One method uses anhydrous ammonia as an input and produces ammonium sulfate, sulfuric acid, or both. Some processes produce only sulfuric acid. Both ammonium sulfate and sulfuric acid are used in the fertilizer industry. Since they can be obtained as byproducts in abatement of undesirable emissions, it is relevant to determine if abatement practices would affect the fertilizer industry.

The primary value of research comes from including all phases of fertilizer production, distribution, and use. Therefore, the findings have specific implications for the industry. Thus, most of this report concerns the implications.

The Michigan Model

The lower two-thirds of the lower peninsula of Michigan served as the fertilizer market area for this study. The 47 counties in this area accounted for approximately 85 percent of the fertilizer consumed in Michigan in 1970, which amounted to 141,932 tons of N, 140,650 tons of P_2O_5, and 155,441 tons of K_2O. However, the findings and implications appear to be relevant to far more than this limited market area. With a few exceptions, they may well apply to most of the Midwest, Northern Great Plain States, Great Lake States, and Northeastern Seaboard States.

The research tool was a systems model based on the linear programing technique. The model was representative of the fertilizer industry in Michigan. Consequently, essentially all components of the Michigan sector of the industry were included. However, regional and national elements of the industry that applied to Michigan markets were also considered. The model and the supporting data are presented in detail in supplemental reports (4 and 15). A brief sketch of the model follows.

Seven basic functions in the industry were contained in the model: production, storage, handling, transportation, processing, sales, and application. These functions are necessary to convert the raw fertilizer materials to fertilizer products and move them to Michigan soil. Thirty fertilizer products were analyzed, 12 of which are

2/ "Optimal" in this report means minimum cost and refers to producing, distributing, and applying fertilizers on Michigan farms at least cost. Unless otherwise specified, "optimal" refers to the long run.

strictly intermediate products. 3/ These intermediate products were nitric acid, nitrogen manufacturing solution, elemental phosphorus, wet-process phosphoric acid, furnace phosphoric acid, ammonium polyphosphate liquids (10-34-0 and 11-37-0), superphosphoric acid, run-of-pile triple superphosphate, run-of-the-mine and standard grades of potassium chloride, and sulfuric acid. 4/ Another 12 products may serve as intermediate products, or go directly to farms for application: anhydrous ammonia, ammonium nitrate, nonpressure and low-pressure nitrogen solutions, urea, ammonium sulfate, normal superphosphate, granular triple superphosphate, monoammonium phosphate, diammonium phosphate, phosphate rock, and granular potassium chloride. Six products are used for direct application only: aqua ammonia, coarse potassium chloride, granulated mixed fertilizers, bulk-blended fertilizers, mixed liquid fertilizers, and suspensions.

Though most products have fixed levels of N, P_2O_5, and K_2O equivalents, formulations and grades of mixed products vary. The model included 140 formulations (representing 18 nutrient ratios) of bulk blends. The 18 ratios represented 80 percent of the fertilizer actually blended in Michigan in 1970. Granulations, liquid mixed fertilizers, and suspensions had 29, 37, and 16 formulations, respectively, included in the analysis.

Six production and processing locations that are possible sources of the fertilizers and can terminate in Michigan were identified. The three primary production areas for N, P_2O_5, and K_2O considered were Donaldsonville, La.; Tampa, Fla.; and Saskatoon, Saskatchewan, respectively. Alternative production locations included a Midwestern location (Peoria, Ill.), a central Michigan location (Lansing), and outstate Michigan locations. Locational alternatives make analysis of relative locational efficiencies possible.

Some products can be produced by more than one technical process. Only significantly different processes were studied, however. For example, dry materials can be blended in several ways, ranging from labor-intensive methods to capital-intensive ones. To represent this continuum, a labor-intensive, a capital-intensive, and an intermediate process were evaluated.

Products may be stored at manufacturing and processing locations, terminals, retailers, or farms, or they may not be stored at all. Usually, however, storage must be provided to reconcile seasonal use of fertilizer with nonseasonal production.

For interstate and intrastate transportation of fertilizer, the primary methods studied were rail, barge, pipeline, and truck. For local hauls from the retailer or mixer to the farm, applicators, trucks, wagons, nurse wagons, and bobtails were included in the model. 5/

When the product alternatives are incorporated with those of process, location, modes and routes of transportation, storage, and sales, a complex system similar to actual industry conditions results. Figure 1 demonstrates this complexity by showing some of the approximately 713,000 separate routes ammonia may take. Thus, the total model is quite involved.

3/ Intermediate products are those used in the production of other fertilizer products.

4/ Sulfuric acid can be purchased, as well as produced, within the industry.

5/ A nurse wagon is a trailer with a tank used to transport liquid fertilizers from the retailer to the applicator in the field. A bobtail is a tank truck (similar to those used to haul propane) that serves the same purpose as the nurse wagon.

PRODUCT FLOW FOR ANHYDROUS AMMONIA

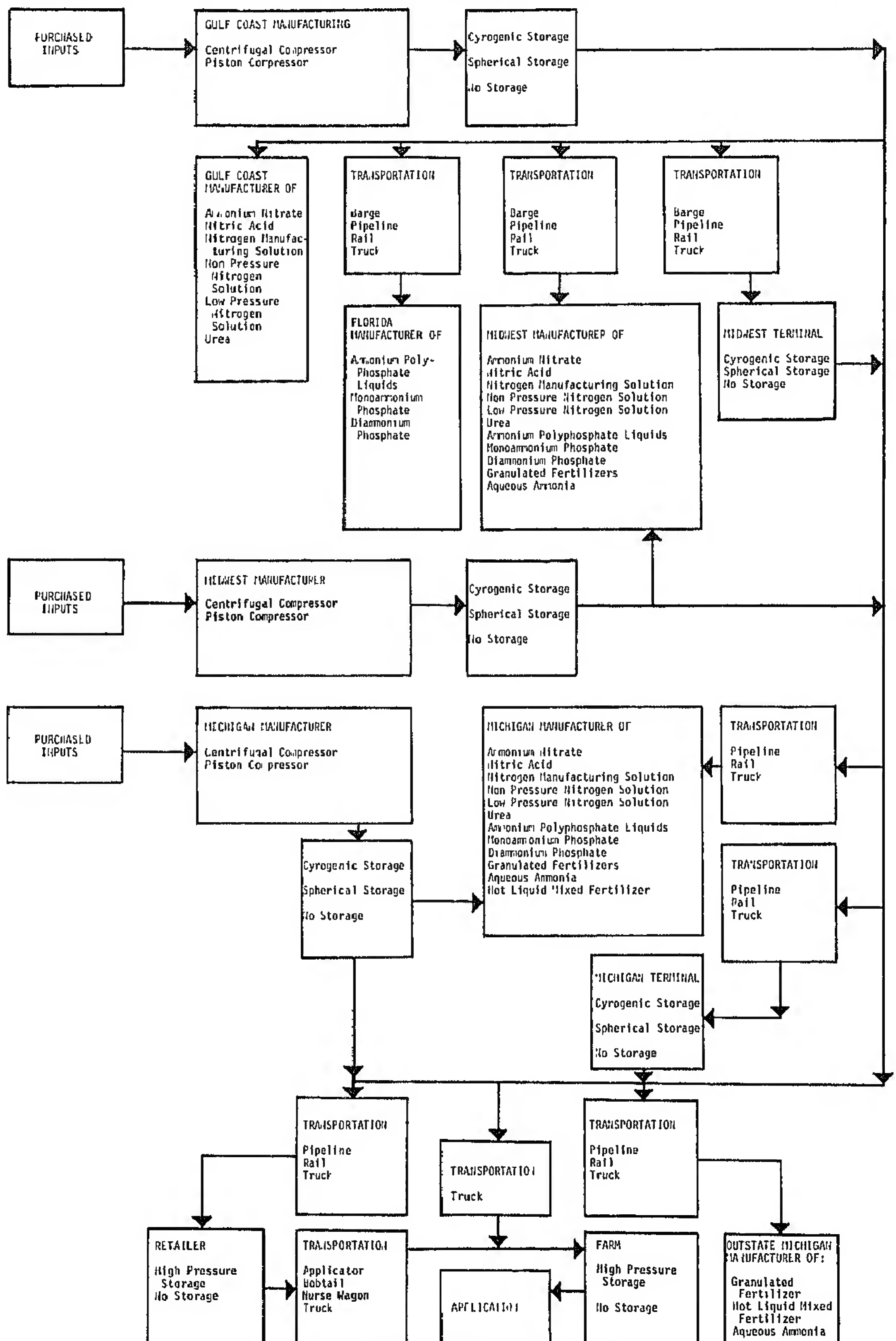

Figure 1

Data

The model was designed so that responses of the industry could be studied adequately and accurately. The model therefore represented the industry rather than a given firm. In addition, costs and technical relationships were handled in a manner consistent with economic analysis rather than accounting practices. Therefore, the data used may not be consistent with or representative of any one firm.

Several hundred publications relating to the fertilizer industry were studied. The intent was to describe the different processes in sufficient detail to allow further investigation and to determine input-output coefficients and other supporting data for the research. After this step was completed, an exhaustive search was made of the relevant literature to develop technical and economic input-output data for the various activities. In the few cases where documented information was not available, assistance was sought from knowledgeable persons associated with the industry.

Once tabulated, the data base was submitted to selected firms in the industry for their evaluation and review. Suggested adjustments were solicited for data that had been questioned by the reviewers. Since each portion of the data was sent to more than one firm with experience in the area questioned, the possibility of a firm bias was avoided.

OPPORTUNITIES AVAILABLE TO THE INDUSTRY FOR IMPROVING PERFORMANCE

The fertilizer industry has many, many parts or components, and they can be combined in numerous ways to supply crops with the required level of nutrients. For example, the purchaser has a choice of over 25 major products, as well as thousands of mixtures. It is difficult to determine which of the numerous possible combinations or components should be recommended to minimize cost.

Unless there is a systematic framework for decisionmaking, management's decisions may not lead to high levels of efficiency without considerable luck. The Michigan model can be used to help make decisions. The following section presents the short- and long-run optimal (minimum-cost) organizations of the fertilizer industry. A brief discussion of implementation is also provided.

The Longrun Least-Cost Organization 6/

Findings indicate that the longrun organization of the fertilizer industry that would meet Michigan farmers' requirements at lowest cost utilizes three basic high-analysis products: anhydrous ammonia, monoammonium phosphate, and granular potassium chloride (table 1). 7/ In this organization, the monoammonium phosphate and granular potassium chloride would be blended to the required ratio of P_2O_5 and K_2O and supplemented with direct application of anhydrous ammonia (fig. 2).

Nearly 173,000 tons of anhydrous ammonia would be used in the longrun organization. Of this amount, about 75 percent would be applied directly on farms while the remaining 25 percent would be used in the production of monoammonium phosphate in Florida (appendix A, table A-2). Direct-application ammonia would be produced in Michigan in a centrifugal plant and distributed by truck directly to farms. In retailing, the emphasis would change from storage and handling to distribution coordination. The rest

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6/ For a more comprehensive discussion of the longrun optimal organization, see: (3, p. 77).

7/ The long- and short-run organizations and the current organization of the industry are presented in detail in appendix A.

of the anhydrous ammonia (43,000 tons) would be produced in the Gulf Coast area in centrifugal plants and shipped via barge to Florida for conversion to monoammonium phosphate (fig. 2).

Table 1.--Product use summary for supplying specified levels of N, P_2O_5, and K_2O to Michigan farmers under alternative organizations

Item	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
	Tons per year		
Total cost (in dollars)	71,445,667	52,555,247	48,297,763
N supplied	141,932	141,932	141,932
P_2O_5 supplied	140,650	140,650	140,650
K_2O supplied	155,441	155,441	155,441
Anhydrous ammonia	164,309	171,894	172,828
Aqueous ammonia	3,897	0	0
Nitric acid	59,832	10,539	0
Ammonium nitrate	78,210	13,777	0
Nonpressure nitrogen solution	40,912	0	0
Low-pressure nitrogen solution	28,171	0	0
Nitrogen manufacturing solution	16,067	19,737	0
Urea	52,006	0	0
Granular ammonium sulfate	35,628	0	0
Elemental phosphorous	4,004	0	0
Furnace phosphoric acid	16,866	0	0
Wet-process phosphoric acid	195,455	236,748	260,565
Superphosphoric acid	207	0	0
Ammonium polyphosphate liquid (10-34-0)	4,832	0	0
Ammonium polyphosphate liquid (11-37-0)	402	0	0
Normal superphosphate	53,791	0	0
Run-of-pile triple superphosphate	138,945	115,303	0
Granular triple superphosphate	26,598	5,274	0
Diammonium phosphate	105,205	77,810	0
Monoammonium phosphate	26,244	99,910	270,576
Rock phosphate	277	0	0
Run-of-mine potassium chloride	111,166	121,462	0
Standard potassium chloride	1,877	0	0
Granular potassium chloride	95,919	137,590	259,032
Coarse potassium chloride	50,000	0	0
Granulated mixed fertilizers	388,555	303,655	0
Bulk-blended fertilizers	203,213	185,535	0
Custom-blended fertilizers	27,785	86,465	529,608
Hot-process clear mixed liquids	11,450	0	0
Cold-process clear mixed liquids	7,633	0	0
Suspension liquids	0	0	0

Note: Appendix A presents these data in greater detail.

OPTIMAL ORGANIZATION OF THE FERTILIZER INDUSTRY FOR SUPPLYING N, P2O5, AND K2O CONSUMED IN MICHIGAN, 1970

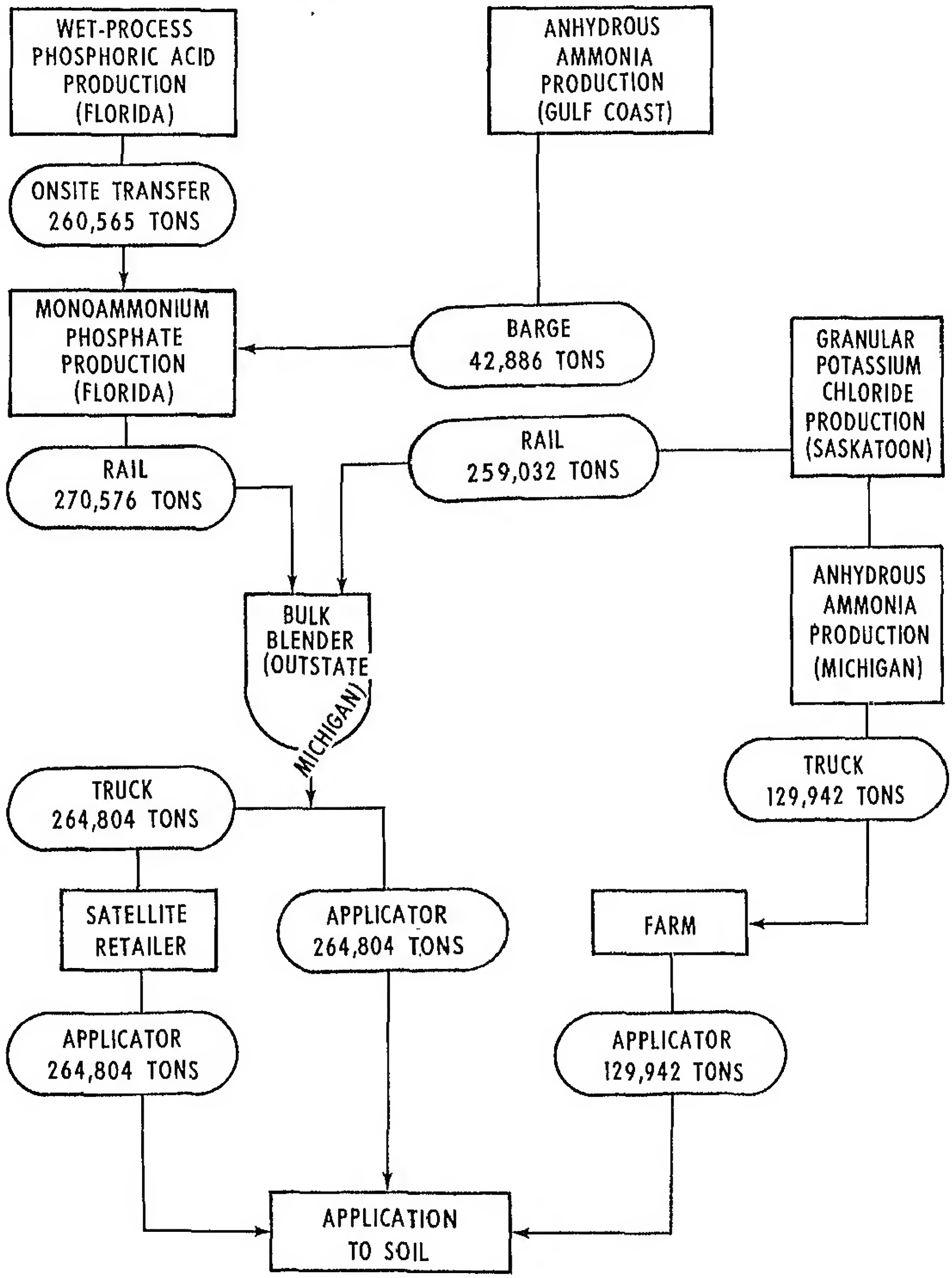

Figure 2

Both monoammonium phosphate and granular potassium chloride would be shipped by rail to large blend plants for production of the appropriate custom blend (appendix A, tables A-21, A-25, and A-30). The alternative sizes examined in the study were plants of 1,000, 2,500, 9,000, and 20,000 tons per year; a plant producing 9,000 tons annually was identified as the most efficient. Although the economies of this larger blender over smaller plants more than offset the increased distribution costs, satellite distribution outlets would be utilized as well to minimize these costs. These patterns vary markedly from the current situation (table 1).

The impact of the longrun optimal organization on the cost of supplying fertilizer is substantial. Whereas the cost of supplying nutrients with the 1970 organization amounted to approximately $71 million, the longrun optimal organization could supply the same amount of nutrients at approximately $48 million, nearly a one-third reduction.

The Shortrun Least-Cost Organization

By definition, investment in new facilities alowed in the long run is not permitted for shortrun adjustments. Nevertheless, the fertilizer industry could make substantial shifts in the short run because of its high level of excess capacity. If all existing facilities had to be used at capacity to meet consumption, production could not be shifted from the less efficient to the more efficient products and activities. However, with industry operations at only 61 percent of capacity existing in 1970, substantial shifts could be made. This opportunity provides the incentive for and feasibility of the shortrun optimal comparison.

To minimize total cost in the short run, direct application of all straight materials except anhydrous ammonia would cease. While direct application of ammonia would more than double, to 128,000 tons, products such as aqua, nitrogen solutions, urea, ammonium nitrate, superphosphates, ammoniated phosphates, and potassium chloride would no longer be used directly on the farm. 8/ Some of these, however, would continue to be used in granulation and bulk blending.

Direct-application ammonia would make up for the loss of nitrogen from other sources while increased use of granulated mix products and bulk blends would supply the P_2O_5 and K_2O lost when straight materials are no longer used for direct application. None of those mixed products would be bagged. Increased use of wet-process phosphoric acid, monoammonium phosphate, and granular potassium chloride as intermediate products would replace the products that would no longer be produced (table 1).

The shortrun organization results in a cost reduction of approximately one-fourth. While the existing organization resulted in a cost of approximately $71 million, the shortrun optimal figure is approximately $53 million. The cost for the longrun optimal organization is $48 million.

Transition to the Longrun Least-Cost Organization 9/

It is assumed that existing facilities would remain in production as long as they can cover variable or cash costs. Additionally, new facilities would not be constructed unless a 15-percent return on investment is expected. The transition is straightforward and much more simplified than expected. The industry first shifts to the shortrun optimal organization. As granulators and small blenders wear out and are closed,

8/ See appendix A, tables A-2 to A-5, A-8, A-18 to A-21, A-23, A-24, A-28, and A-30.

9/ For a thorough discussion of the transition, see (22, p. 1).

they are replaced with the new large-scale blenders.

As the granulators, one by one, cease to operate, the facilities that produce the materials used in granulations would lower their production level, while the facilities that supply the bulk blenders with inputs would increase their output (table 2).

Although the transition is relatively simple, those firms that would become sub-optimal or relatively more costly in the long run would tend to resist the change. These firms have to protect existing investments. Nevertheless, the prospects of a reduction in total cost of over 32 percent suggests that the longrun optimal industry organization should be seriously considered and pursued.

Table 2.--Product use summary during transition years from existing to shortrun to longrun optimal organization

Product	Year 1/					
	0	1	2	3	4	5
	Tons per year					
Anhydrous ammonia	171,974	172,327	172,473	172,619	172,763	172,763
Nitric acid	9,930	5,147	3,432	1,716	0	0
Ammonium nitrate	12,980	6,729	4,486	2,243	0	0
Nitrogen manufacturing solution	18,596	9,640	6,427	3,213	0	0
Elemental phosphorus	3,977	1,591	795	0	0	0
Furnace phosphoric acid	16,866	6,746	3,373	0	0	0
Wet-process phosphoric acid	220,645	242,603	249,688	256,774	260,487	260,487
Run-of-pile triple superphosphate	115,303	53,687	35,687	17,894	0	0
Granular triple superphosphate	8,352	0	0	0	0	0
Diammonium phosphate	111,857	59,586	42,709	25,833	0	0
Monoammonium phosphate	72,737	170,321	201,070	231,823	270,495	270,495
Run-of-mine potassium chloride	114,440	59,323	39,551	19,772	0	0
Granular potassium chloride	144,629	179,704	209,469	239,241	259,006	259,006
Coarse potassium chloride	0	20,000	10,000	0	0	0
Granulated mixed fertilizers	286,099	148,308	98,887	49,431	0	0
Bulk-blended fertilizers	272,000	245,699	288,543	331,400	374,243	374,243
N supplied	141,932	141,932	141,932	141,932	141,932	141,932
P_2O_5 supplied	140,650	140,650	140,650	140,650	140,650	140,650
K_2O supplied	155,141	155,141	155,141	155,141	155,141	155,141

1/ Year 0 corresponds to the adjustment to shortrun minimum-cost organization, which, by definition, can take place immediately. Years 1 through 5 project the replacement of facilities used in the shortrun by facilities that produce least-cost fertilizers in the long run. For a thorough discussion of this transition, consult: (22, p. 1).

Distribution of the Savings

How would the savings that result from reducing cost one-fourth in the short run or one-third in the long run be distributed between fertilizer firms and farmers? Although the allocation cannot be accurately determined, certain considerations are helpful.

As farmers discontinue using more inefficient products and begin trying efficient products, they will immediately realize lower costs for their nutrients. And as they increasingly bypass their local retailers and small-scale mixers, their costs will be lowered further. Since further savings depend on investment in new facilities at new locations, which would not occur until current facilities are physically depreciated, the remaining potential savings would be slow in coming. Thus, at first glance, farmers would seem to receive most of the benefits.

However, as demand for the efficient products at the efficient locations increased, their price could be drawn upward, particularly if few firms offered such products. As fertilizer prices rose, some of the benefits would be transferred from farmers back to fertilizer firms. Therefore, the final distribution depends on the extent of price competition. If price competition continues to follow the pattern of the last few years, farmers would receive the bulk of the benefits.

It is reasonable to expect that benefits would accrue to both groups. Fertilizer firms probably could not support a price high enough to prevent farmers from receiving benefits. On the other hand, firms would not be likely to engage in price competition that would pass most of the benefits on to farmers. Yet if they did, these firms would be better off than many firms are now, since the calculations include a reasonable return on their investment as a normal cost of operation. Of course, with the reorganization, numerous existing facilities would be phased out, and several companies would probably go with them. Therefore, while the surviving firms would be better off, it would be at the expense of firms that leave the industry.

CHANGES IN CONSUMPTION PATTERNS 10/

Throughout the preceding analysis, total consumption of N, P_2O_5, and K_2O was assumed constant at the 1970 level. It was further assumed that farmers and suppliers would and could adjust to the optimal mix of products once it was known. In this section, the impact of relaxing these assumptions is examined.

The 141,932 tons of N, 140,650 tons of P_2O_5, and 155,441 tons of K_2O purchased in fertilizer materials by Michigan farmers in 1970 represent a ratio of the nutrients N-P_2O_5-K_2O of 1.009-1.0-1.105, or close to 1-1-1. As long as fertilizer nutrients are consumed in this ratio, the short- and long-run least-cost organizations are relevant. For example, if consumption of N, P_2O_5, and K_2O each increased by 20 percent, the facilities used in the least-cost organization would be utilized, but at higher levels. 11/ On the other hand, if the ratio of nutrients consumed changed, adjustments from the short- and long-run least-cost organizations would have to be made.

10/ For a rigorous discussion of the information in this section, see (14).

11/ In the short run, with consumption at current levels, some facilities would be operating at capacity while others would be used at levels well below capacity. As nutrient consumption increased, these latter facilities would run at higher levels. Consumption could increase to 154 percent of the 1970 level before these facilities would be at capacity. At higher consumption levels, other facilities would also have to be used. In the long run, when additional facilities can be built, there is virtually no limit on the capacity of the optimal organization to supply increased quantities of fertilizer, assuming adequate capital and other resources would be available and directed into the fertilizer industry.

There is reason to believe that the relative consumption of fertilizer nutrients will change over time. In the past, the nutrient ratio of fertilizers consumed in Michigan changed from approximately a 1-5-3 ratio in 1950 to the current 1-1-1 ratio in 1970. The trend line over the past 20 years shows that, until recently, consumption of P_2O_5 exceeded that of either N or K_2O, while consumption of both N and K_2O increased more rapidly than that of P_2O_5. By 1970, more N and K_2O were consumed than P_2O_5 (fig. 3). From 1950 to 1970, consumption of P_2O_5 increased at a compound annual rate of 3.8 percent; K_2O consumption increased by 6.7 percent and N, by 12.5 percent (9, p. 56).

It is uncertain how the consumption of fertilizer nutrients will change relative to each other in the future. However, past trends plus projections of nutrient demand in Michigan indicate that most likely the consumption of N will increase relative to both K_2O and P_2O_5 and use of K_2O will rise relative to P_2O_5. Based on several studies projecting fertilizer consumption in Michigan (3; 7, pp. 14-17) and on actual use of plant nutrients by crops harvested there (14, p. 30), the ratio of fertilizer nutrients consumed in Michigan could approach 2.3-1.0-1.8 in the near future.

Based on this projected ratio, an investigation was conducted into the effect of relative increases in both N and K_2O consumption on the optimum organization of the industry. The effect of a rise in P_2O_5 consumption relative to N and K_2O was also investigated, though the possibility of such an increase appears remote.

PLANT NUTRIENT CONSUMPTION, MICHIGAN, 1950-70

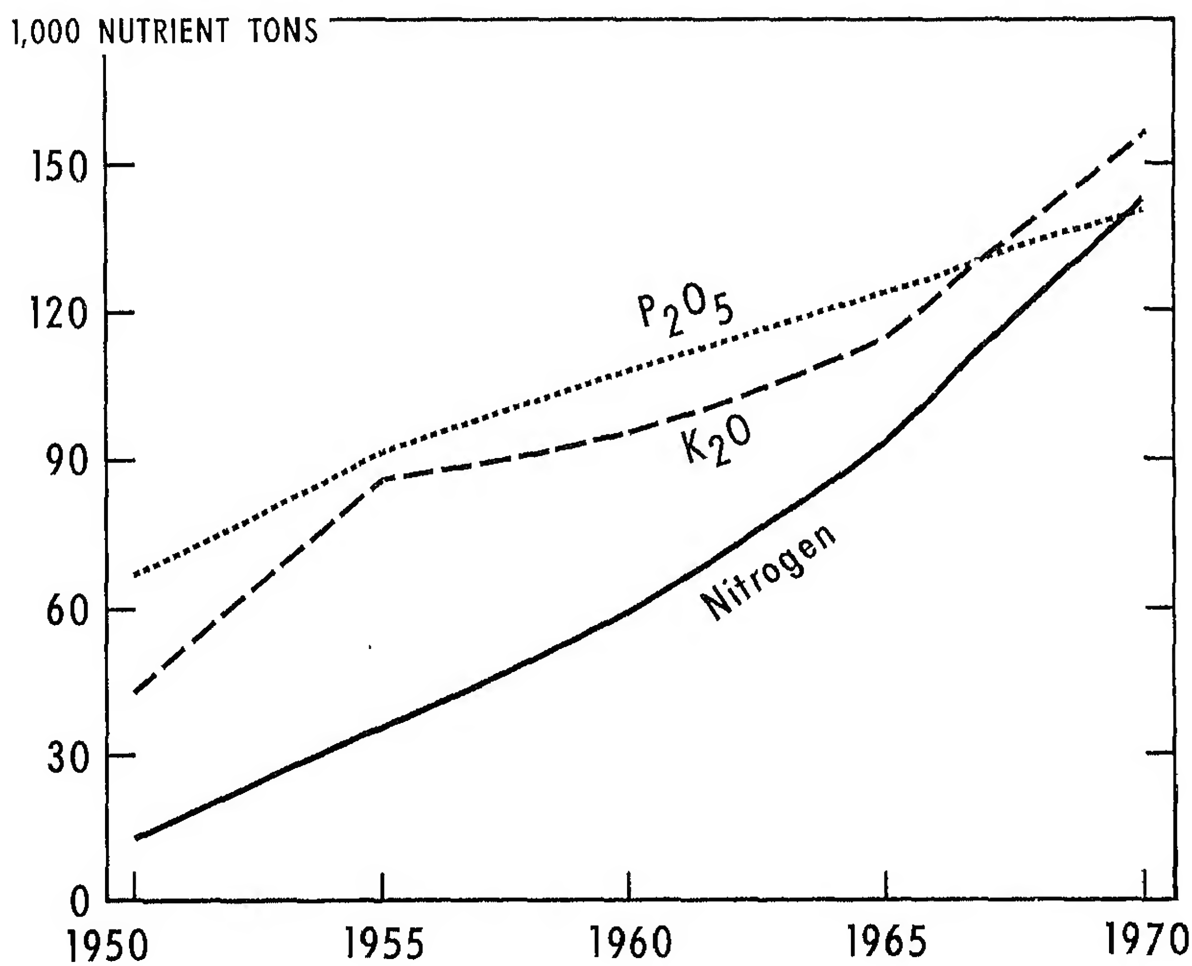

Figure 3

Nutrient Changes with Current Facilities

Increased Nitrogen Consumption

An increase in consumption of N relative to other nutrients can be supplied at the lowest cost by raising, in the short run, production of anhydrous ammonia for direct application. A 20-percent increase in N consumption can be supplied by uniformly increasing ammonia production at all locations. The distributional pattern for ammonia and the per ton cost for providing an incremental ton of N to Michigan farms remains unchanged (fig. 4 and app. B, tables B-1 and B-2).

If consumption of N rises more than 20 percent but less than 40 percent, a change in ammonia distribution from midwestern and Gulf Coast producers is necessary. Midwestern ammonia, which is distributed to midwestern nitric acid manufacturers at the current level of nitrogen consumption, is diverted to direct distribution in Michigan, when nitrogen consumption is raised more than 20 percent. Midwestern nitric acid producers, in turn, receive their ammonia from Gulf Coast producers. These distributional changes cause the per ton incremental cost of N to go up from $108.33 to $109.25, or less than 1 percent.

Substantial changes in ammonia distribution are necessary as consumption of N increases more than 40 percent, given shortrun conditions in the industry. Such a large increase in the purchase of N exceeds the distribution capacity of local suppliers. While it is economically feasible to distribute ammonia produced in the Midwest directly to Michigan farms, direct-application ammonia produced at the Gulf Coast would be efficiently supplied through local retailers. As retailing capacity becomes exhausted, the economically attractive pattern for distributing additional quantities of ammonia from the Gulf Coast to Michigan farms would be to use an ammonia terminal located in the Midwest. N could most economically be transported to the terminal by barge and distributed directly to Michigan farms. These shortrun distribution changes raise the average incremental cost per ton of N about 6 percent to $115.04.

Increased Potash Consumption

Some interesting changes occur in the least-cost industry organization as K_2O consumption grows relative to P_2O_5, particularly in the shortrun organization, K_2O is supplied to Michigan farms in granulated 6-24-24 and bulk-blended 7-28-28. As consumption of K_2O increases relative to P_2O_5, a custom-blended fertilizer with a 1-3-6 nutrient ratio replaces some of the blended 7-28-28. That is, a fertilizer high in K_2O relative to P_2O_5 replaces the product with equal parts of the two nutrients. As a result, use of monoammonium phosphate in the blended 7-28-28 drops and use of diammonium phosphate in the custom-blend product rises. Correspondingly, use of granulated 6-24-24 increases to assure the proper nutrient mix (fig. 5 and app. B, table B-3).

When K_2O consumption increases about 35 percent, all existing capacity to produce granulated 6-24-24 fertilizer is used. Furthermore, all existing large-scale blending capacity in the State is employed in producing the 1-3-6 ratio custom blend. Thereafter, additional quantities of K_2O can be supplied most economically as granular potassium chloride for direct application. This material can be provided in the short run by existing local retailers.

These changes in product mix and distributional facilities required for shortrun increases in K_2O consumption raise the average cost of providing an incremental ton of K_2O 5 percent, from $102.36 to $107.67.

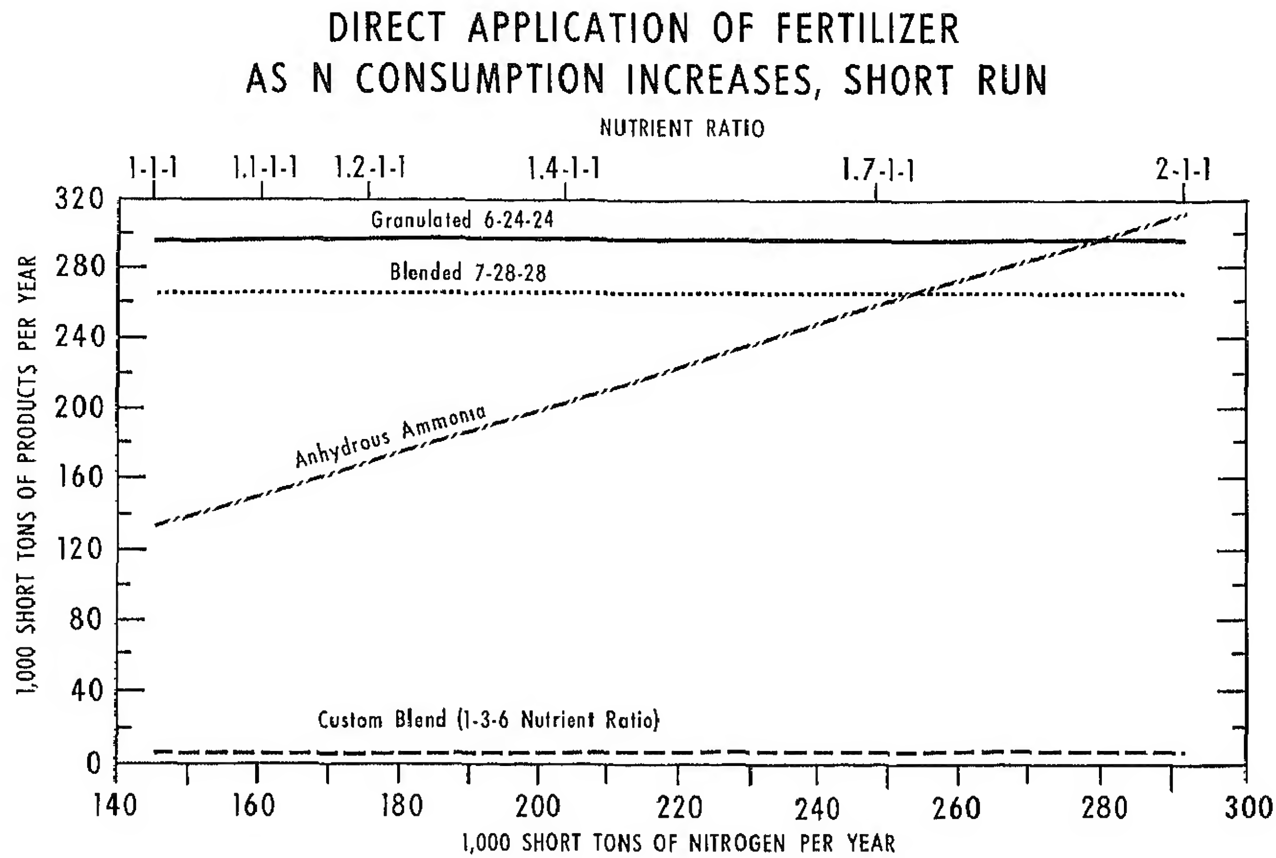

Figure 4

Increased Phosphate Consumption

While the probability of relative increases in P_2O_5 consumption is low, the necessary adjustments in the industry are more far-reaching than if changes occur in consumption of the other major fertilizer nutrients. Ties between the supply of P_2O_5 and other nutrients in the form of N-P_2O_5 and N-P_2O_5-K_2O materials are closer than is true for either N or K_2O. That is, though both N and K_2O are frequently applied as straight single-nutrient fertilizers, P_2O_5 is usually applied in a material that contains one or both of the other primary nutrients. In the longrun optimal product mix, there is no material included containing only P_2O_5. Thus, relative changes in the P_2O_5 supply may have important effects on the supply of N and K_2O, whereas changes in N and K_2O, supplies may not alter the P_2O_5 supply.

The shortrun optimal organization of the fertilizer industry is very sensitive to relative increases in P_2O_5 consumption. If P_2O_5 consumption increased 10 percent relative to the other nutrients, both diammonium and monoammonium phosphate would be used as direct-application materials (fig. 6). Prior to this change, all P_2O_5 would have been provided in mixed and blended products. When relative use of P_2O_5 goes up 10 percent, use of 1-3-6 custom blend fertilizer ceases. If relative consumption of P_2O_5 were to increase more than 10 percent, the existing bulk-blending capacity in Michigan would be diverted to producing larger quantities of a 1-4-1 ratio custom blend and smaller amounts of 7-28-28. Previously idle capacity for producing granulated mixed fertilizers would be used to produce the greater quantity of 6-24-24 necessary to achieve the proper nutrient balance. These changes require a steadily increasing production of both monoammonium and diammonium phosphates and their attendant ingredients, particularly phosphoric acid (app. B, tables B-4 to B-15).

DIRECT APPLICATION OF FERTILIZER AS P_2O_5 CONSUMPTION INCREASES, SHORT RUN

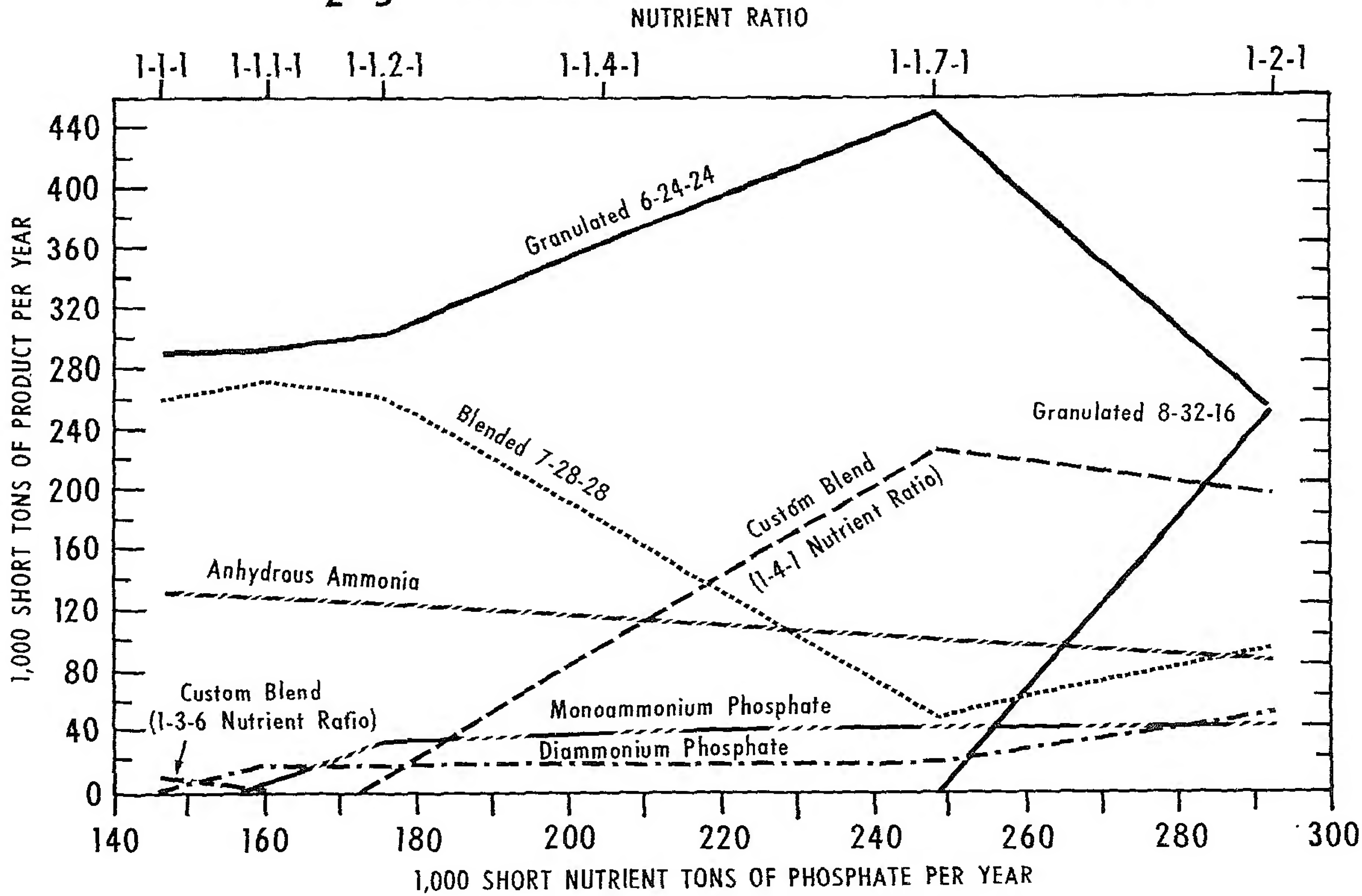

Figure 5

DIRECT APPLICATION OF FERTILIZER AS K_2O CONSUMPTION INCREASES, SHORT RUN

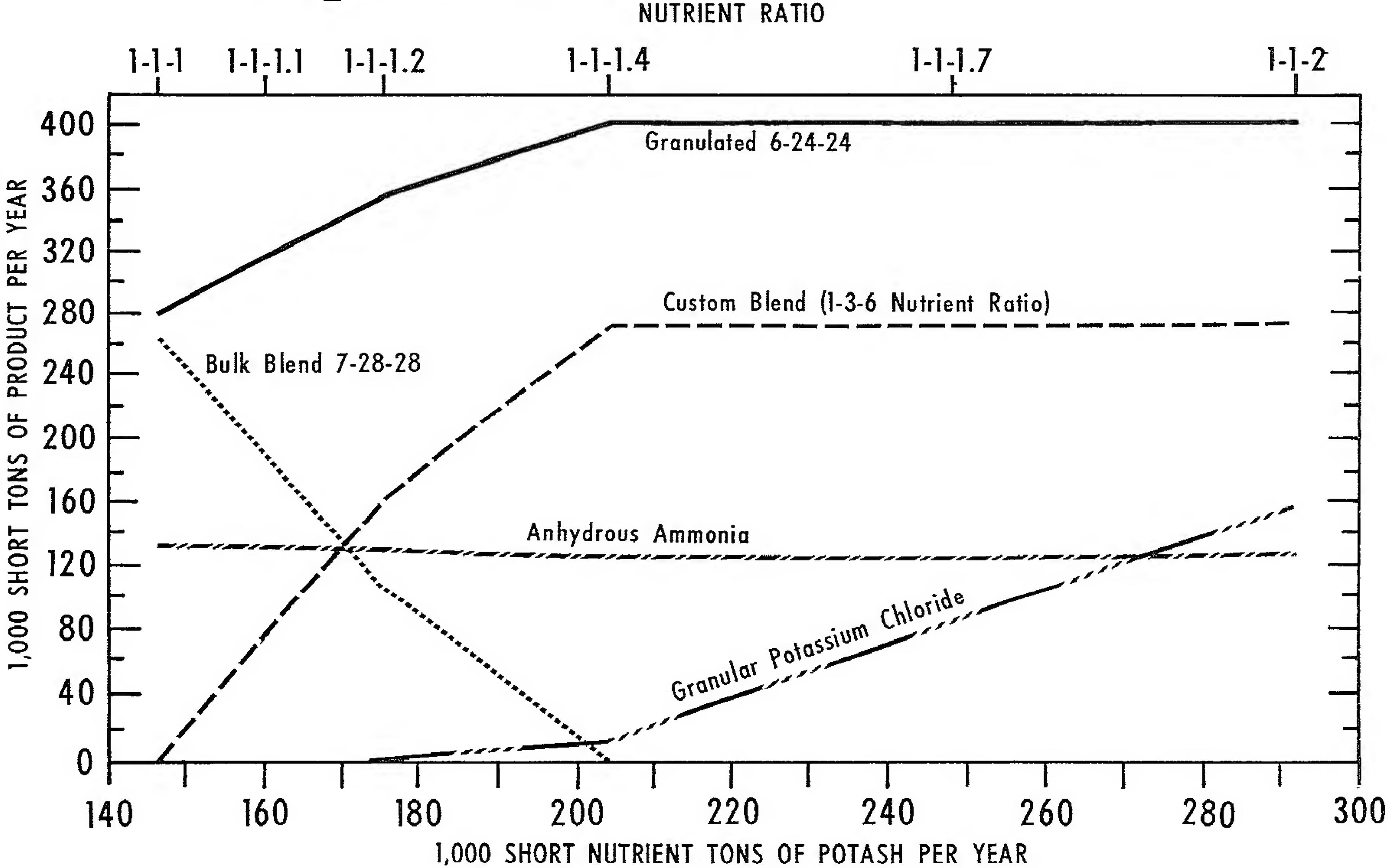

Figure 6

Total ammonia production is not affected in the shortrun structure, although its distribution changes; some would be diverted from direct application to ammoniated phosphates production. In addition, increased production of nitrogen ammoniated solutions, run-of-pile triple superphosphate, and run-of-mine potassium chloride is required to produce the additional quantities of granulated mixed fertilizers. Corresponding with the greater use of run-of-mine potassium chloride is a decrease in use of granular grade potash.

In the short run, these changes, necessary to supply relatively high amounts of P_2O_5, raise the average cost of providing an incremental nutrient ton of P_2O_5 about 6 percent, from \$154.23 to \$163.44.

Nutrient Changes in the Long Run

Changes in the ratio of nutrient consumption in the longrun plan cause substantially fewer changes than in the short run, because new facilities can be constructed in the long run in response to changes in the ratio. In Michigan, as nitrogen consumption rises relative to that of the other two nutrients, the only adjustment required is increased production of anhydrous ammonia for direct distribution to farms. This expansion does not affect the average cost of providing an incremental ton of nitrogen.

Relative increases in potash consumption are also simply facilitated. In the longrun optimal organization, P_2O_5 and K_2O were supplied by mixing those amounts of monoammonium phosphate and potassium chloride that provided these two nutrients in their appropriate ratio. Therefore, as the level of K_2O consumption increases in the long run, the only adjustment is to raise the level of granular potassium chloride used in the mixture to meet the new ratio. Thus, production of granular potassium chloride would have to increase and more large-scale blend plants would be needed to produce the custom blend. As the ratio of K_2O-P_2O_5 increased, the greater mixing costs could be allocated to the K_2O, making its cost higher.

Relative growth in the consumption of phosphate is satisfied similarly. Increasing the amount of monoammonium phosphate in the bulk blend will result in larger quantities of phosphate. This change requires the production of relatively greater quantities of monoammonium phosphate, along with a larger amount of phosphoric acid (used as an input in the production of monoammonium phosphate). Ammonia distribution would shift away from direct application to the manufacture of ammoniated phosphate. These longrun changes would slightly increase the average costs of providing an incremental ton of P_2O_5 in the blended fertilizers as more of the blending costs logically would be allocated to P_2O_5.

Suboptimal Products

Several products used in Michigan in 1970 were not included in the short- or longrun optimal mixes of products. Likewise, some products that were optimum in the short run were suboptimum and left out in the long run (table 3). There may be preferences in the market for some of the higher cost products, particularly because many of them were used in substantial quantities in 1970. It is important to know how costs and industry organization are affected by such preferences.

Table 3.--Fertilizers used in direct application, Michigan

Product	Current industry organization (1970)	Shortrun least-cost organization	Longrun least-cost organization
	Tons per year		
Anhydrous ammonia	62,082	128,338	129,942
Aqueous ammonia	3,897	0	0
Ammonium nitrate	27,704	1/0	0
Nonpressure nitrogen solution	39,803	0	0
Low-pressure nitrogen solutions	2,155	0	0
Urea	24,047	0	0
Ammonium sulfate	2,740	0	0
Normal superphosphate	371	0	0
Granular triple superphosphate	3,608	1/0	0
Diammonium phosphate	6,838	1/0	0
Monoammonium phosphate	3,269	1/0	2/0
Rock phosphate	277	0	0
Potassium chloride	61,996	1/0	2/0
Granulated mixed fertilizer	388,555	303,655	0
Dry-blended fertilizer	203,213	185,535	0
Custom blends	27,785	86,465	529,608
Liquid mixed fertilizer	19,083	0	0

1/ Used as a direct-application material in 1970, this product appears in intermediate form in the shortrun optimum product mix but not as a direct-application product.
2/ This product is used as an intermediate product in the longrun optimum but not for direct application.

Source: (20).

Ammonium nitrate, nonpressure nitrogen solutions, urea, granulated mixed fertilizer, and mixed liquid fertilizers were all sold in relatively large quantities in 1970. Each accounted for 2 percent or more of all direct-application materials, but each was an economically unattractive product in the industry. Likewise suspended liquids, a relatively new type of mixed fertilizer, conceivably could be demanded by some Michigan farmers in the future, though this study shows suspension fertilizer to be a higher cost product. Apparently, six suboptimal products may be preferred by sellers, buyers, or both, in the future. Three of these products (liquid mixtures, nonpressure nitrogen solutions, and urea) were not used in the shortrun optimum though capacity currently exists to handle them. None of the six appears in the longrun optimum. An analysis was conducted to determine (1) the additional cost to the system if each of these products were purchased by Michigan farmers in lieu of the minimum-cost products, and (2) the effects of such purchases on the least-cost mix of products.

Mixed Liquids

If clear mixed liquid fertilizers are used in the short run, the least-cost grade is 4-12-24 with inputs of ammoniated polyphosphate (10-34-0), standard grade potassium chloride, and nonpressure nitrogen solution (28-0-0). Each ton of this product used adds $4.10 to the total cost of supplying fertilizer nutrients to Michigan farmers and displaces 0.77 ton of granulated mixed fertilizer.

In the long run, the least-cost grade of clear liquids is also a 4-12-24 mixture, but furnace phosphoric acid is used as a source of P_2O_5 rather than ammoniated polyphosphate. Each ton of this fertilizer displaces 0.632 ton of blended fertilizer and a small amount, 0.012 ton, of direct-application ammonia. The cost in the industry is $6.14 per ton more than the total cost when only optimal products are used. The longrun excess cost is higher than the shortrun excess because mixed liquids displace granulated mixed fertilizer in the short run, but displace blended fertilizers in the long run. Blended fertilizers are a less expensive source of fertilizer nutrients than mixed liquids. Thus, high excess costs exist with the continued use of the economically suboptimal liquid form. Therefore, criteria other than minimum costs would be needed to support the continued use of this product.

Nonpressure Nitrogen Solutions

A second type of direct-application fertilizer shown to be suboptimum in both the short and long run is nonpressure nitrogen solution. In the short run, each ton of this product displaces 0.341 ton of direct-application anhydrous ammonia and requires an attendant increase in production of the intermediate fertilizer materials used in manufacturing the solution, including nitric acid, ammonium nitrate, and urea. Each ton of nonpressure solution used by farmers in the short run adds $26.36 to the cost of supplying the same quantity of plant nutrients using the least-cost combination products.

The consequences of continued use of nonpressure nitrogen solution are much the same in the long run. Again, each ton used for direct application displaces 0.341 ton of direct-application ammonia and requires greater production of the attendant input materials. The additional cost for each ton of nonpressure solution used in the long run is $15.98. Though this figure is $10.38 less than the corresponding shortrun cost, the drain on financial resources of industry participants remains substantial. Thus, if use of this economically suboptimal product is continued, in either the short or long run, other factors than cost need careful consideration.

Urea

Urea is a third product that is economically suboptimum in both the short and long run. In many areas of the Midwest, urea has not been very important as a direct-application fertilizer. In Michigan, however, the product has accounted for about 2.5 percent of total fertilizer tonnage used. When used, each ton of urea displaces 0.548 ton of direct-application ammonia. No other direct-application materials are affected. The most economical means of producing urea appears to be the ammonium carbamate slurry process in a plant located in the consuming area. Michigan lacks such a facility. Thus, if urea is used in the short run, production facilities in other areas must be used, which is less efficient. In the short run, $23.16 is added to total costs for each ton of urea used. In the long run, during which time production facilities could be constructed in Michigan, this cost falls to $9.69 per ton. In either case, urea adds substantially to the cost of providing fertilizer nitrogen for Michigan farms.

Ammonium nitrate

Another straight nitrogen fertilizer not included in the longrun optimal product mix is ammonium nitrate. When direct-application ammonium nitrate is used in the longrun product mix, each ton displaces 0.341 ton of direct-application ammonia and production of nitric acid as an ingredient must be increased. For each ton of ammonium nitrate used, $21.90 is added to the total cost of providing plant food nutrients to Michigan farms. In other words, the cost per ton of nitrogen goes up 56 percent relative to the least-cost alternatives. This extra cost is substantially greater than the excess costs associated with the use of urea in the long run. Therefore, if a dry form of nitrogenous fertilizer is used in place of direct-application anhydrous ammonia, urea would apparently be less costly than ammonium nitrate.

Suspensions

The longrun use of suspended liquid fertilizer was investigated, though little of this product is currently being applied on Michigan farms. The least costly suspension formulation was determined to be a 26-13-0 grade, with nonpressure nitrogen solutions and ammoniated polyphosphate (11-37-0) as primary inputs. Suspended 26-13-0 has a significant impact on other products in the longrun optimal mix. Each ton used displaces 0.277 ton of direct-application ammonia and approximately one-quarter ton of custom blend. The ratio of the custom blend is changed slightly to supply the altered remaining nutrient requirements. An additional cost of $6.89 is generated by each ton of suspensions used, amounting to 16 percent over the minimal per ton nutrient costs in the long run. This excess represents $0.75 per ton more than the costs associated with longrun use of clear mixed liquid fertilizer, indicating that suspensions are less attractive economically in Michigan than clear liquids.

Granulated Fertilizers

Granulated mixed fertilizer is the last product studied that was not included in the longrun least-cost fertilizer mix. Granulations were an economical product in the shortrun optimum. If they are produced in the long run, the least-cost ratio is 6-24-24, with run-of-pile triple superphosphate, diammonium phosphate, and run-of-mine grade potassium chloride as principal inputs. Each ton of the granulated fertilizer displaces approximately 0.85 ton of custom blend and brings about a corresponding decrease in the use of monoammonium phosphate and granular grade potassium chloride. No other direct application materials are affected. Each ton of granulated 6-24-24 used imposes an extra cost of $1.96 on the system, or about a 3.3-percent increase in nutrient costs. Thus, with a slight change in the relationship between the cost of

input materials or of manufacturing granulated mixtures and the cost of blended fertilizers, granulations may be economically feasible over a longer period.

Obviously, minimizing the cost of fertilizer by reorganizing the industry would require farmers to purchase substantially different products than they did in 1970. Ammonium nitrate, nonpressure nitrogen solutions, urea, and liquid, granulated, and suspended mixed fertilizers are alternatives but all impose higher costs on both the industry and farmers. These costs can be avoided.

ENVIRONMENTAL CONCERNS AND THE FERTILIZER INDUSTRY 12/

Society is becoming increasingly sensitive to damages caused by air pollution. The sulfur oxides, which are exceedingly dangerous for most inorganic materials as well as plant and animal life, are receiving much of this attention. Existing legislation designed to control sulfur oxide emissions has been ineffective. However, on February 8, 1972, President Nixon laid before the Congress a program to clean up and protect the environment. Included was a proposal to levy a tax on sulfur oxides discharged into the atmosphere. 13/ The tax, which would not apply until 1976, would be 15 cents per pound of sulfur emitted in regions where primary air-quality standards have not been met, and 10 cents per pound in regions where secondary standards have not been met (21, p. 4).

Numerous processes designed to recover sulfur oxides from the flue gas of coal-burning electric power generating plants, which account for approximately one-half of all sulfur oxide emissions, are in varying stages of development and use. Although some of these processes produce products of insufficient value to be marketed, most produce sulfuric acid, and a few produce ammonium sulfate.

Both ammonium sulfate and sulfuric acid are used in the fertilizer industry. Ammonium sulfate is employed both as a fertilizer material and in the manufacture of other fertilizer materials. Sulfuric acid is used primarily in the acidulation of phosphate rock, the initial step in producing phosphate fertilizers.

Since ammonium sulfate, sulfuric acid, or both can be obtained as byproducts in abating undesirable emissions from the power generating industry, their price could, theoretically, fall below zero if the powerplant had to pay for their disposal. Consequently, these two products could enter the fertilizer industry at a wide range of prices. Entering at competitive prices, these products could affect the fertilizer industry substantially. In addition, if they were to generate a sizable return to the power firm, some, or perhaps all, of the abatement cost could be recovered without a rise in the price of electricity.

In the study, three uses of the byproduct ammonium sulfate were examined: (1) value as an input into producing a granulated mixed product, (2) value as an in-

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12/ For a comprehensive discussion of the information in this section, see: (3, p. 77).

13/ Given the goal of minimizing the cost of pollution, the tax approach is economically sound if the tax is set at a level commensurate with the damage caused by the sulfur. The taxed firm can determine the best adjustment to make in light of costs and benefits. If the firm could reduce emissions at a cost that would be less than the charge, it would do so to avoid being assessed the tax. If it could not reduce the emissions at a cost less than the charge, the firm would pay the tax, but would nevertheless have a continuing incentive to reduce emissions. Firms that could afford neither method would be forced to discontinue production. Thus, a cost that had been external to the firm would become internal, and pollution would be minimized. An economic analysis of this and other approaches is presented in (3, p. 77).

put into bulk blends, and (3) ability to compete as a direct-application product with other sources of nitrogen. The feasibility of using byproduct sulfuric acid recovered from Michigan powerplants in acidulating phosphate rock in Michigan and Florida was also examined. In all cases, the byproducts were evaluated for their ability to compete with the products in the longrun least-cost organization.

Ammonium Sulfate Used in Granulated Mixed Products

Ammonium sulfate as an input in producing a granulated 20-20-0 product can compete with the optimal products only at very low prices. Not until the price of ammonium sulfate falls to \$1.40 per ton is this input competitive. At this price, the N in the ammonium sulfate would replace some of the N in the anhydrous ammonia that was being applied directly. Since the granulated mixture would also provide some phosphate, the level of monoammonium phosphate in the bulk blend would decline to ensure that the required levels of P_2O_5 and K_2O are present. Additional similar shifts would occur as the price of ammonium sulfate fell to \$0.70 and \$0.30 per ton (table 4). If the price of ammonium sulfate fell to zero, no further shifts would occur.

The potential savings from substituting ammonium sulfate for anhydrous ammonia and the associated shifts are small. With ammonium sulfate priced at zero, the total cost of supplying the amount of N, P_2O_5, and K_2O consumed in Michigan in 1970 would fall from \$48,297,763, the cost under optimal conditions without the ammonium sulfate, to \$47,865,328, only 0.9 percent.

Blending With Ammonium Sulfate

The use of the byproduct ammonium sulfate for bulk blending was also examined. Although this byproduct is usually recovered as a fine powder from powerplants, it is relevant to determine if efforts should be directed to develop technology for converting ammonium sulfate to granular form. If it would be economically competitive in blending, such efforts may be warranted.

Granular ammonium sulfate would not be economically competitive with the optimal product mix until its price fell to \$12.50 per ton. However, only a small amount would be used, 13,054 tons, accounting for less than 2 percent of total nitrogen consumed. Lowering the price \$1 to \$11.50 per ton would cause a small increase in consumption, but no further shifts would occur until the price fell extremely far, to \$1.50 per ton. At that figure, the 193,116 tons of granular ammonium sulfate could be used, replacing anhydrous ammonia used for direct application and accounting for 29 percent of the nitrogen consumed. An additional drop to \$1 per ton would cause another large increase in consumption, up to 279,448 tons, or 43 percent of total nitrogen consumption. At this price, the remaining nitrogen would be supplied in anhydrous ammonia (32 percent); and in monoammonium phosphate (25 percent), which is used in bulk blending (table 5).

As was the case when ammonium sulfate was used for granulating 20-20-0, the total cost of supplying fertilizer would change little as increasing amounts of ammonium sulfate are used in bulk blending. With ammonium sulfate priced at zero, the cost of providing the N, P_2O_5, and K_2O would be \$47,621,040, a saving of only 1.4 percent compared with the longrun optimum.

Direct Application of Ammonium Sulfate

Using byproduct ammonium sulfate in direct application was also examined. Although the relevant technology for the powdered form is not well developed, it was assumed that this byproduct can be handled, stored, transported, and applied at the same cost as granular ammonium sulfate.

Table 4.--Quantity of powdered ammonium sulfate used in granulated mixed fertilizers at alternative price

Granulated mixed fertilizer	Price of ammonium sulfate: Greater than $1.40 per ton	Less than $1.40 but greater than $0.70 per ton	Less than $0.70 but greater than $0.30 per ton	Less than $0.30 per ton
	Tons per year			
Anhydrous ammonia, direct application	129,942	97,169	57,627	57,557
Ammonium sulfate production	0	190,068	396,300	420,168
Granulated mixed fertilizer (20-20-0)	0	179,309	373,868	396,385
Bulk blend	529,608	460,536	393,357	377,065

Table 5.--Quantity of granular ammonium sulfate used in bulk blending at alternative prices

Bulk blend fertilizer	Price of ammonium sulfate: Greater than $12.50 per ton	Less than $12.50 but greater than $11.50 per ton	Less than $11.50 but greater than $1.50 per ton	Less than $1.50 but greater than $1.00 per ton	Less than $1.00 per ton
	Tons per year				
Anhydrous ammonia, direct application	129,942	124,242	119,805	75,849	54,194
Granular ammonium sulfate production	0	13,054	23,042	193,116	279,448
Monoammonium phosphate production	270,576	270,823	270,900	270,893	270,961
Bulk blends	529,608	542,985	553,039	723,078	809,527

Although ammonium sulfate used for direct application is competitive at low prices only, large amounts would be used. At $2 per ton, 296,321 tons of ammonium sulfate would be used in direct application, accounting for 45 percent of the nitrogen consumption. At $1 per ton, the figure would be 508,629 tons, or 75 percent of nitrogen consumption. In both cases, the ammonium sulfate would replace anhydrous ammonia; in the former, 75,703 tons and in the latter, 129,942 tons (table 6).

The savings generated would be more than in either of the other two uses, but not great. With free ammonium sulfate, the total cost of fertilizer would be $47,454,707, a saving of 1.7 percent.

In conclusion, ammonium sulfate competes with N in the longrun optimal organization only at very low prices. However, only the value of nitrogen in the ammonium sulfate was considered. The sulfur content in ammonium sulfate is greater, and scientists have recently recorded crop responses to sulfur applications on some soils. If a value is imputed for the sulfur, the ammonium sulfate might be competitive at substantially higher prices.

On the other hand, ammonium sulfate is nearly three times as acidic as the alternative sources of nitrogen. Consequently, the sulfate should be limited to soils with a high Ph, or its value should be discounted to account for the higher levels of lime needed to counteract its acidity.

Finally, the byproduct ammonium sulfate was evaluated for its ability to compete with the longrun optimal products. These products would provide the nutrients purchased by Michigan farmers at nearly one-third less cost than did the products actually purchased in 1970. Thus, the byproduct ammonium sulfate could probably compete with products currently used and at much higher prices. 14/

Electricity Versus Sulfuric Acid for Producing Phosphoric Acid

Though only those abatement processes that use anhydrous ammonia as an input produce ammonium sulfate, many other processes can produce sulfur or sulfuric acid. Unlike ammonium sulfate, sulfuric acid has known value in the fertilizer industry. At current prices, it is an established input for producing wet-process phosphoric acid. The major alternative is to produce furnace phosphoric acid from elemental phosphorus which is manufactured using an electric ARC furnace. Electricity is the major cost factor. An analysis was made, therefore, of prices for electricity that would make this alternative competitive with the sulfuric acid or wet process.

With the price of sulfuric acid at $12 per ton 15/, furnace phosphoric acid would not be competitive until the price of electricity fell to 1.254 mills per kw.-hr., a price significantly lower than the current 4 mills for off-peak power. At 0.226 mills, furnace phosphoric acid would completely replace wet-process phosphoric acid. If the price of sulfuric acid were $16 per ton, furnace phosphoric acid would be competitive at 3.297 mills, completely replacing the wet-process form at 2.268 mills. (Table 7 shows the rate at which furnace acid replaces wet acid when sulfuric acid is priced at $12 and $16 per ton.)

14/ A study is currently underway to determine the competitive potential of byproduct ammonium sulfate with the products currently used in Michigan.

15/ Although the current price of sulfuric acid is $12.32 per ton, $12 per ton was used to simplify the analysis.

Table 6.--Quantity of powdered ammonium sulfate used in direct application

Price of ammonium sulfate (Dollars per ton)	Anhydrous ammonia			Ammonium sulfate		
	Total production	Applied directly	Stored	Total production	Applied directly	Stored
	Tons per year					
$2	172,828	129,942	54,239	0	0	0
2	97,125	54,239	54,239	296,321	296,321	0
1	42,886	0	0	508,629	508,629	212,309
0	42,886	0	0	508,629	508,629	212,309

Table 7.--Quantity of white phosphoric acid substituted for green phosphoric acid at alternative prices 1/

Product	Price of sulfuric acid ($12 per ton)					
	Pe=4.00 2/	Pe=1.2545	Pe=0.6131	Pe=0.3700	Pe=0.2686	Pe=0.2259
	Tons per year					
Elemental phosphorus production	0	15,660	20,480	30,716	56,982	61,422
Furnace phosphoric acid production	0	66,413	86,852	130,264	241,655	260,485
Wet-process phosphoric acid production	260,565	194,073	173,649	130,236	18,846	0
Monoammonium phosphate application	0	68,965	90,189	90,189	90,189	90,173
Sulfuric acid	383,031	285,288	255,264	191,488	27,704	0
Electricity (1,000 kw.-hr.)	0	191,421	250,330	375,456	696,512	750,786
	Pe=4.00	Pe=3.2970	Pe=2.5756	Pe=2.4101	Pe=2.3087	Pe=2.2677
	Price of sulfuric acid ($16 per ton)					

1/ Substitution of furnace phosphoric acid for wet-process phosphoric acid follows the same pattern when sulfuric acid is priced at $12 per ton as it does at $16 per ton, only prices for electricity differ. Therefore, tonnages relate to price relationships at the bottom of the table as well as at the top.

2/ Pe=The price of electricity in mills per kw.-hr.

As production of furnace-process phosphoric acid increasingly replaces wet-process acid, production of monoammonium phosphate shifts from Florida to Michigan. This change directly reflects advantages of transporting the highly concentrated elemental phosphorus (229 percent P_2O_5 equivalent) rather than the monoammonium phosphate (52 percent P_2O_5). Although the production of monoammonium phosphate shifts, output remains stable. In the optimal organization, all of this phosphate is used in bulk blending, but when monoammonium phosphate is produced in Michigan, approximately one-third of it is applied directly.

Thus, at current prices ($12 per ton for sulfuric acid and 4 mills per kw.-hr., of electricity), the elemental phosphorus-phosphoric acid alternative cannot compete with the sulfuric acid-phosphoric acid alternative. However, facilities exist for producing elemental phosphorus and furnace phosphoric acid. As long as they return some amount on the investment (above and beyond operating costs), closing them would be irrational. Consequently, the return on investment was set at zero to determine if such plants would become competitive with those producing sulfuric acid. When the price of sulfuric acid is $12.32 and electricity is 4 mills, the sulfuric acid-wet process phosphoric acid is cheaper, and no elemental phosphorus is used. Therefore, based on efficiency, the elemental phosphorus plants should be shut down, even in the short run. The variable cost of producing P_2O_5 and getting it to the soil via the elemental phosphorus-furnace phosphoric acid route is greater than the total production cost with wet-process phosphoric acid.

Such products as diammonium and monoammonium phosphate and ammonium polyphosphates are not optimally produced in the Michigan area. If they are produced, the necessary phosphoric acid is best provided with the elemental phosphorus method. Though the wet process is preferred under optimal conditions, the elemental phosphorus-furnace phosphoric acid method can supply phosphoric acid to Michigan at less cost than the wet process.

Byproduct Sulfuric Acid in Michigan

In the ammonium sulfate analysis, the byproduct was assumed to be produced at powerplants in Michigan. However, in the sulfuric acid analysis, prices used were those at the Florida phosphate plants. These assumptions were satisfactory for analyzing the substitution between sulfuric acid and electricity. But it cannot be inferred that byproduct sulfuric acid from scrubbing powerplants in Michigan has the same opportunity as sulfuric acid in Florida. Consequently, use of byproduct sulfuric acid for acidulating rock phosphate in Michigan was examined. Even if the price of the byproduct sulfuric acid fell to zero, it was not cheaper to produce phosphoric acid in Michigan than in Florida (with sulfuric acid at $12.32 per ton), where the acid is used to produce monoamminium phosphate for consumption in Michigan. Further, shipping the byproduct sulfur from Michigan to Florida was not economical.

IMPLICATIONS: BASIC PRODUCTION AND TRANSPORTATION

Nitrogen Producers

Using anhydrous ammonia in direct application was found to be the most economical method of supplying nitrogen fertilizer in Michigan. Additional amounts were supplied in the ammoniated phosphates used in bulk blending. Other sources of nitrogen, such as ammonium nitrate, urea, low-pressure and nonpressure nitrogen solutions, and aqueous ammonia impose unnecessary costs on the industry and its consumers.

Consumption patterns of nitrogen products indicate that consumers are increasingly substituting ammonia for other sources of nitrogen, particularly in the last year or

two (Fig. 7). As these consumers strive to minimize their expenditures on fertilizer while maintaining or increasing the level of nutrient consumption, they will continue to replace other sources of nitrogen with ammonia, as long as prices in the industry accurately reflect costs.

Statisticians at the Tennessee Valley Authority estimate that, in 1970, 48 firms had the capacity to produce 6,916,000 tons of ammonium nitrate in 75 plants in the United States. In that same year, 46 plants owned by 39 firms had a capacity of 4,360,000 tons of urea (12). Anhydrous ammonia will provide stiff competition as farmers continue to switch. Thus, these firms need to evaluate their specific situations to determine the most appropriate procedure for disinvesting in facilities used for ammonium nitrate and urea production. Since the conversion to anhydrous ammonia will not occur in a year or two, the firms involved would probably find it possible to continue producing the nitrate and urea for the fertilizer market until their plants are depreciated.

In 1970, U.S. consumption of nitrogen solutions was over 3 million tons. Michigan farmers used only 40,000 tons. Though a ton of nitrogen costs up to $50 more if supplied in the form of nonpressure nitrogen solution than in the form of ammonia, the 1970 consumption levels of nitrogen solutions were considerably higher than those in 1969. A reversal of this trend would be expected, based on comparative economies, but farmers' preferences for the handling characteristics of liquid fertilizers may slow the conversion. Since nitrogen solutions are used in liquid mixes as well as in direct application, their future depends on farmers' preferences. Additionally, the compatibility of nitrogen solutions with pesticides as a post-emergence "weed and feed" application on many crops may give these products advantages not reflected in the least-cost analysis.

As expected, the large-scale centrifugal compressor plants allow more efficient ammonia production and distribution than do the smaller piston compressor plants. In addition, there is a premium on the development of large-scale ammonia production facilities in the market area. It is cheaper to manufacture anhydrous ammonia in Michigan using natural gas that either originates in the area or is transported there than to produce the ammonia on the Gulf Coast and transport it to the fertilizer market. Implied is a longrun decrease in the importance of ammonia production capability in the Gulf Coast area, contrary to the trend that has developed recently in the industry. Most of the newly constructed ammonia producing plants have been built in the Gulf Coast region rather than near the major consuming areas.

Several factors may have stimulated this trend. First, an abundant supply of natural gas has existed in the Gulf Coast region. This readily accessible feedstock and its relatively low price has undoubtedly lured numerous plants. Second, and closely related, firms may believe the supply of natural gas is more dependable in the Gulf Coast area than in the fertilizer consuming areas. There is less risk of natural gas shortage on the Gulf Coast due to limitations within the gas transmission system. Gas distribution priorities are such that when shortages occur in the North, ammonia producers there have to restrict their production, which is a costly exercise.

Third, by locating on deepwater routes, a firm has greater marketing flexibility. If the U.S. marekt price becomes depressed, the firm can switch to the international market. Fourth, the concentration of chemical complexes in the Gulf Coast area offers additional markets for anhydrous ammonia. Much of the ammonia is converted to other fertilizer and nonfertilizer products for both U.S. and international markets. For example, the ammonia may be used to produce urea, a major export product; ammonium phosphates in Florida; and a wide range of nonfertilizer products, such as acrylonitrile and chemical grade urea.

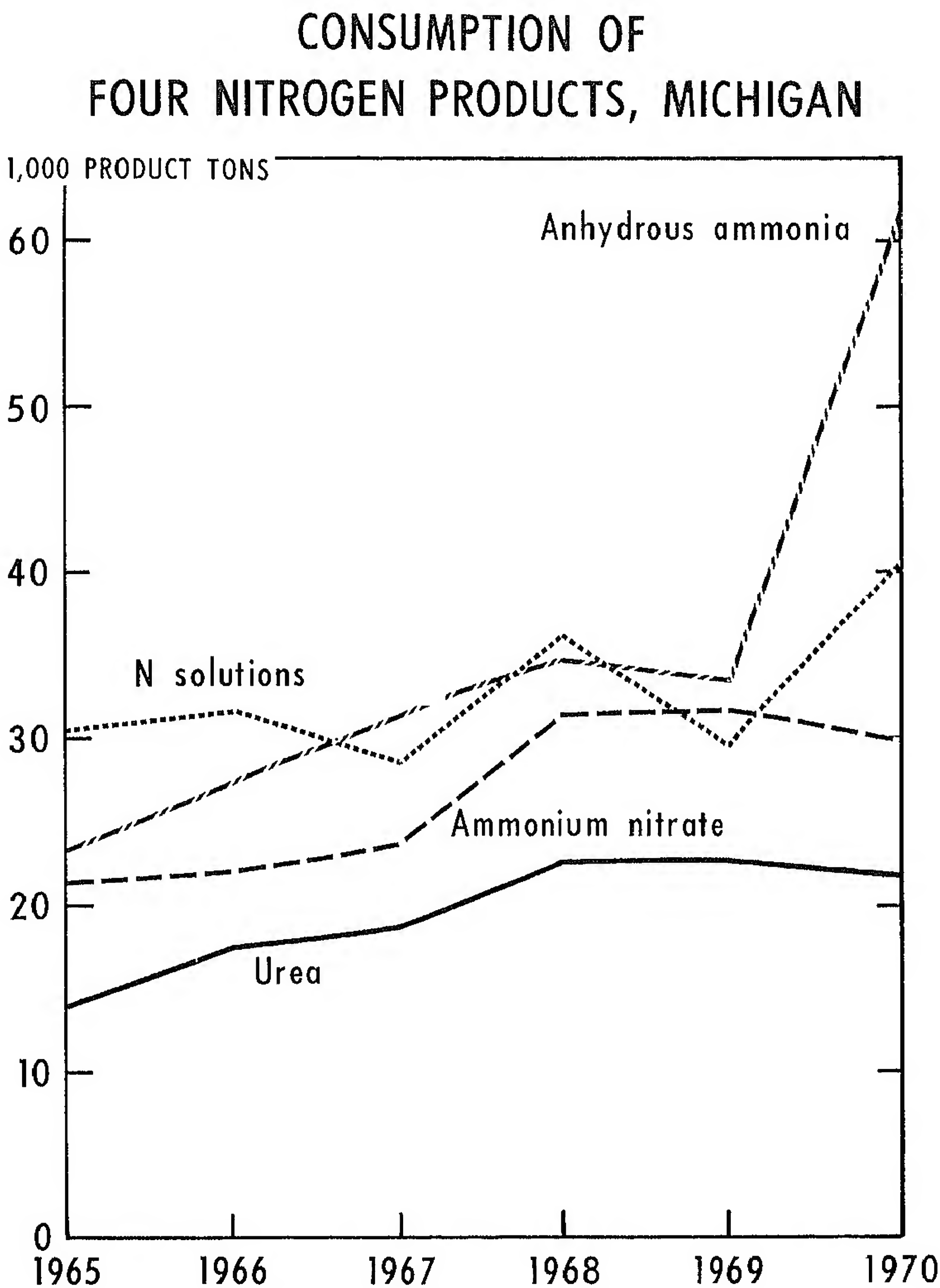
CONSUMPTION OF
FOUR NITROGEN PRODUCTS, MICHIGAN
1,000 PRODUCT TONS
60
50
40
30
20
10
0
Anhydrous ammonia
N solutions
Ammonium nitrate
Urea
1965
1966
1967
1968
1969
1970

Figure 7

Although the international market has been strong, it is currently a poor outlet for U.S. producers who find the domestic market unsatisfactory. U.S. exports have declined because of reductions in Agency for International Development purchases and stiff competition from other gas-rich nations whose expansion in fertilizer production has matched or exceeded that of the United States. As some of these countries have become self-sufficient in fertilizer production, they too have turned to the world market. The increased competition was sufficient to cause a price decline, and as other countries have searched worldwide for potential markets, U.S. imports have increased significantly. In addition, several less developed countries that traditionally relied on imports now have their own production facilities. These trade problems will exist for the United States for several years (11, p. 32).

Compared with costs at the alternative locations, producing anhydrous ammonia is certainly cheaper with lower cost natural gas which usually can be found in the Gulf Coast area. But when the more complete processes of production and distribution are considered, the advantage swings to production in the market area. How significant the risk of an unsteady supply of natural gas and the associated cost to the firm would be depends on numerous factors unique to each firm, including its production and distribution system. These factors could not be evaluated effectively here.

Although piston compressors are much less efficient than centrifugal compressors, existing piston plants in Michigan should not be shut down. By accepting a lower return on investment, these plants can compete with centrifugal plants on the Gulf Coast. Consequently, Michigan firms can expect stiff competition, but unless returns fall below the plant's salvage value, production should continue. Of course, implications for future investments are clear.

Generally, ammonia is stored most cheaply in cryogenic vessels. Although operating costs tend to run higher for cryogenic tanks than for high-pressure tanks, the investment is considerably less. However, capacity of the cryogenic tanks limits their use to only manufacturing plants and terminals. Storage on a small-scale basis, such as at retailers or farms, requires smaller, high-pressure tanks. Since cryogenic storage is cheaper, costs are thus minimized if ammonia is stored at the manufacturing plant. Handling costs can be minimized and product investment is at its lowest. For example, if producing 1 ton of ammonia costs $20 and transporting it to a terminal costs $10, a $30 per ton investment is tied up in the stored product at the terminal. Only a $20 investment would be tied up if the product were stored with the manufacturer. Therefore, serious attention needs to be focused on developing storage capacity for ammonia at manufacturing points while maintaining a storage system consistent with timely product delivery.

Phosphate Producers

P_2O_5 and K_2O were found to be supplied at lowest cost when monoammonium phosphate and granular potassium chloride were used in blended fertilizer in which the two nutrients were combined in the appropriate ratios. The cost of producing and distributing P_2O_5 to blenders was least when the monammonium phosphate was produced near the Florida rock phosphate mines. This finding implied that basic phosphate production has moved away from areas near fertilizer consumption to Florida. This trend, which has actually developed recently, appears economically justifiable and should continue. Also, ammoniated phosphates are being favored over superphosphates and concentrated superphosphates as a basic source of P_2O_5. Increased use of these phosphates appears also to be justified economically.

Implications of these findings for operations are clear. Phosphate producers should place high priority on deactivating superphosphate and concentrated superphospate plants, particularly those located away from the phosphate mines. Although both

monoammonium and diammonium phosphates are economically superior products, existing ammoniated phosphate capacity near the southeastern rock mines can most efficiently be used to produce monoammonium phosphate, from an industrywide viewpoint. Since anhydrous ammonia is the lowest cost carrier of nitrogen, producing monoammonium phosphate (13-52-0) is preferable since the amount of nitrogen carried is minimized (compared with diammonium phosphate 18-46-0), while the high analysis characteristic of the ammoniated phosphates is maintained. As existing capacity becomes a constraint in the industry, priority should be placed on investment in new ammoniated phosphate facilities in the Southeastern United States.

The future of elemental phosphorus depends on its nonfertilizer uses and suboptimal uses in the fertilizer industry. At current electrical rates and sulfur prices, production of elemental phosphorus in the electric arc furnace and its conversion to phosphoric acid in the furnace process do not compete in cost in the fertilizer industry with that of phosphoric acid produced by acidulating rock phosphate with sulfuric acid. Since the price of sulfur is expected to remain low in the long run (see later sections of this report), this relationship will probably not change for some time.

However, if phosphoric acid is used as an input in producing basic phosphoric fertilizers in the Northern United States, the acid can be supplied at minimum cost with the elemental phosphorus method. This low cost results from the technical option of producing phosphoric acid from elemental phosphorus. The elemental phosphorus can be produced at the phosphate mine and shipped as a highly concentrated product (229 percent P_2O_5 equivalent) to the North, where the product will be converted to phosphoric acid. The higher cost of producing phosphoric acid with this process is offset by the savings in transportation costs. Of course, if the elemental phosphorus was converted to phosphoric acid in Florida and transported to the North, the savings resulting from transporting the highly concentrated product would not be realized, and the cost advantage would again lie with the wet process. Thus, if the furnace plant for converting elemental phosphorus to phosphoric acid is in the North, phosphoric acid can be supplied there by the elemental phosphorus route cheaper than through the wet-acid process.

Producing phosphate products in the North, however, is not as efficient as producing monoammonium phosphate in Florida and shipping it to the North. Therefore, use of elemental phosphorus in the fertilizer industry depends on the geographically suboptimal location of production facilities for phosphate fertilizers. There are other opportunities in nonfertilizer uses. These options justify continual evaluation as producers of elemental phosphorus face increased price competition in the fertilizer markets.

Potash Producers

In the long run, granular grade potassium chloride is included in the optimal product mix, while in the short run, both granular and run-of-mine grades are important. The shortrun mix of run-of-mine and granular grades is produced by screening off different-sized materials as the product comes out of the benefication process. To some extent, the ratio of relatively fine or run-of-mine material to coarse or granular material can be controlled within the refining process itself. Such control provides the flexibility to produce the grades in different ratios. In the short run, these adjustments can be made to produce the proper ratio of these two grades.

In the long run, meeting product specifications will be difficult. To produce only the granular grade product will require a modification in benefication technology. Therefore, the potash producers should give priority to developing improved refining processes to effect the production of relatively large quantities of the granular product.

Carriers

As the fertilizer industry moves toward its longrun least-cost organization, the carriers of its products, including railroads, trucks, barges, and pipelines, will also have to make some rather substantial adjustments. Expansion of phosphate production in Florida will require additional rail capability and rolling stock for moving ammoniated phosphate products into the consuming areas. Corresponding with the recent trend in the development of more phosphate facilities in Florida has been the shortage of rail equipment for transporting phosphate products. Continuation of the trend to move facilities will place greater demands on the rail industry. In total, the amount of of rolling stock required to move phosphate products probably will not change much. However, some of the stock has been cars with open tops, used to carry rock phosphate. Shipping monoammonium phosphate will require enclosed hopper cars.

Transportation is complicated by the seasonal nature of fertilizer use. Many of the rail cars used for shipping phosphate products are needed only 6 months of the year. Thus, dual-purpose cars were developed that could transport fertilizer, grain, or other similar bulk products. More of these cars are needed to meet demands of the phosphate industry during the peak fertilizer season.

Under the longrun optimal organization, most phosphate would be stored at the point of production. During the fertilizer consumption season, the phosphate would be distributed to bulk blenders located throughout the market area. Thus, the period for phosphate shipments would be more concentrated than under current conditions. Also, more rolling stock and improved coordination in the railroad industry would be needed. Though such developments may be desirable for the fertilizer industry, railroad management would become more complex. Not only would railroads need to increase their investments, they would also have to find additional complementary uses for their equipment in the slack fertilizer season.

Considering both the fertilizer and railroad industries, less resources might be required if storage were moved to the blending location. Although fertilizer storage costs would be higher, far fewer railcars would be needed, and they could be used entirely for hauling fertilizer. Under this arrangement, as the phosphate was produced in Florida, it would be transported to the blenders located throughout the market area. By spreading the distribution activities from a very short season to a year-round operation, a continuous flow of phosphate would result, requiring far less rolling stock and greatly simplifying coordination.

The increased cost resulting from storing the product at blenders in the market area would amount to approximately $300,000. Assuming the average railcar carries 40 tons, 6,764 carloads of phosphate would be involved. Assuming further that an assigned railcar could make a round trip in 20 days and that the fertilizer consumption season lasted 3 months, approximately 1,500 railcars would be required to move the fertilizer to Michigan from storage in Florida. On the other hand, if the fertilizer were shipped to the blenders immediately upon production, a yearlong activity, only 375 cars would be necessary. If some of the cars were used for hauling some products back to the Gulf Coast or Florida area, more time would be needed, but efficiency might be improved. In either case, the $300,000 storage premium might be a small price to pay for the benefits that could be derived from storing the phosphate product at the blenders in Michigan.

The situation involved in transporting the 260,000 tons of potash from Saskatchewan mines to the blenders in Michigan is similar to the phosphate situation. Paying a storage premium would reduce greatly the resources necessary for moving potash to Michigan by rail. Otherwise, the problem of coordinating the cars during the brief

fertilizer season and finding alternative uses for them in the off-season might be substantial.

The shift in ammonia production away from the Gulf Coast has implications for both rail and pipeline carriers. Much of the Gulf Coast ammonia has been transported to Michigan by rail. If the nitrogen industry shifted geographically, there would be less demand for this rail service. However, a regional shift in ammonia production would require a corresponding shift in the transmission of natural gas, which is moved primarily by pipeline. Limited pipeline capacity has been a factor in the reported shortage of natural gas in Michigan. Thus, to effect the regional shift in ammonia production, means would have to be developed for increasing Michigan's supply of natural gas. Two alternatives are available for exploration. The first would be to increase the capability of the current gas transmission system. The second would be to switch some of the carrier capability being used for ammonia to natural gas.

Trucks carry ammonia from the centrally located point of production to the farmers. Since much ammonia has been moved in the State by rail, more trucks would be required than are currently in use, if the second alternative is chosen. As in transporting phosphate and potash products, the demand for trucks to ship ammonia is highly seasonal. Therefore, during a sizable portion of the year, these trucks could be used for other purposes. But there are few alternatives. Only high-pressure gases, such as natural gas or liquefied petroleum, are well suited for handling in these trucks. Although the liquefied petroleum gas season complements the ammonia season, demand for the gas may not be great enough to utilize all the trucking capacity.

In conclusion, carriers can generally expect a steadily increasing market for transporting fertilizer products. Distribution of monoammonium phosphate from Florida will increase substantially while distribution of ore from that location and the transportation of other phosphate products will diminish. Distribution of all nitrogen products from the Gulf Coast will decrease while ammonia distribution from Central Michigan will increase and more natural gas will move into Michigan.

IMPLICATIONS FOR THE FERTILIZER INDUSTRY IN MICHIGAN

Mixers

According to results of this study, substantial changes are desirable in the mixing sector of the Michigan fertilizer industry.

Bulk Blenders

In the long run, nutrient costs would be minimized by mixing monoammonium phosphate and granular potassium chloride in large bulk blenders capable of handling about 9,000 product tons annually. 16/ At least 60 such plants would be needed through Southern Michigan to minimize the cost of supplying fertilizer nutrients to farmers in the area. As many as 75 plants or more may be required as fertilizer consumption increases over the next 10 years.

16/ The 9,000-ton-per-year blender was seen as the best of the alternatives considered. However, it cannot be said that this size is better than the 5,000-, 7,000-, or 11,000-ton sizes, since these were not considered. A 9,000-ton-per-year blender is a large operation, not easily achieved. Some may argue that a 6,000-ton-per-year plant is more feasible, and is nearly as efficient as the 9,000-ton size. However, if the 6,000-ton size is used, the number of plants and the distribution system would need to be adjusted accordingly.

Since only a few of the existing blenders in the state can operate at the 9,000-ton level, more large scale blenders would be needed. And even if the new blenders utilized some facilities of existing blenders, over half the existing blenders would have to be phased out. Each new blender would need a satellite-warehouse system for distributing its product in the least costly manner. These warehouses are similar to facilities currently used for retailing dry bulk fertilizers, and, in many cases, the bulk outlets could be used. But, as with blenders, not all the warehouses would be required, and the remainder would have to be phased out.

Based on the number and age of blend plants in the State, replacing existing plants with larger scale plants would probably begin slowly and reach a peak near the end of the 1970's. Michigan had only two dry-blend plants in 1959, 23 in 1964, 55 in 1966, 73 in 1968, and approximately 105 in 1970 (10; 20). If the productive life of a blend plant is 10 years, the older plants should be physically exhausted by 1980, and the number of plants that wear out or become obsolete annually should reach approximately 15 per year. While some plants may remain productive beyond 1980, others would probably close earlier because of poor operating and maintenance or other economic factors. As the existing plants become unable to meet blending demands, they should be expanded or phased out and replaced with larger plants.

Because the blenders' advantage is in providing phosphate and potash, these units should minimize the nitrogen blended in their final product. Since nitrogen can be supplied most efficiently as anhydrous ammonia, it would not be desirable economically to sacrifice high levels of phosphate or potash in the blended product to increase the nitrogen level.

Phosphate and potash levels can be balanced to the individual farmer's requirements in custom-blended fertilizers. 17/ Although phosphate and potash consumption is near 1:1 ratio in Michigan, individual requirements vary substantially. By changing the ratio of these products used in the blending operation, a wide range of mixtures can be achieved.

Optimally, monoammonium phosphate and granular potassium chloride are the best sources of P_2O_5 and K_2O, respectively, for blending. While there are different grades of granular potassium chloride, alternative K_2O-bearing products are few and none of them are competitive economically. Although some firms use a coarse grade of potassium chloride for blending, the granular grade blends with other granular inputs to produce a more nearly homogeneous product with less tendency to segregate; thus, this grade is a superior product for blending.

Monoammonium phosphate is excellent for blending because it is a high-analysis product, carrying the highest phosphate level among basic phosphate products. Of all fertilizer products, only anhydrous ammonia has a higher nutrient content. Although diammonium phosphate is a high-analysis product too, its nitrogen level is higher and its phosphate level lower than those of monoammonium phosphate. Consequently, diammonium phosphate is usually less desirable in blending. However, in some situations, such as fertilizing sod or fruit trees, using anhydrous ammonia might be impossible because of its application requirements; and the higher nitrogen content of diammonium phosphate might be preferable. Nitrogen in the blend can also be increased by including urea in the formulation.

17/ Michigan laws require that a fertilizer firm license each grade it markets in Michigan, or be licensed as a custom mixer. Therefore, whereas most blenders currently license the grade they market, with the optimal organization, being licensed as a custom blender would be preferable.

Granulators

Although their longrun prospects are not as bright as those for blenders, granulation plants will also continue to be productive in the near future. The cost associated with ammoniating-granulating mixed products is sufficiently great to put these products at a competitive disadvantage as a lasting source of nutrients. But if production is continued with a low return on investment, such mixed products would remain a reasonably good source until large-scale blending operations can supply the phosphate and potash requirements. Ammoniation-granulation plants in Michigan are generally nearing the end of their productive life and several have already been closed. Discontinuing production in the remaining plants, over the next several years, should not cause undue economic hardships for those firms. As with bulk blenders, ammoniator-granulators can best be used to produce products high in phosphate and potash.

Since granulated mixes cost less than liquid mixes and suspensions, they might be expected to remain part of the product mix longer than the two fluids. However, the continued use of fluids will result from their physical rather than economic characteristics. Since granulated mixes have neither the handling advantages of fluids nor the economic advantage of bulk blends, they come out second best by either criterion. Consequently, their importance as a source of fertilizer nutrients will decline.

Liquid Mixers

Implications for liquid mixers are clear. Neither suspensions nor liquid mixes are economically competitive with dry blends, in the long or short run. In the long run, nutrients supplied in clear liquid mixes would cost at least $15.35 per ton extra, while the premium paid for nutrients in suspensions would be higher.

Implications of the extra high costs associated with producing and distributing suspension fertilizer are not too serious. There are no established suspension plants in Michigan. Consequently, no firms are faced with the task of marketing these products. But for any firm that anticipates producing and distributing suspensions the message is clear; a strong competitive disadvantage exists.

Michigan does have several clear-liquid mix plants; there were four in 1959, 10 in 1964, 12 in 1966, and 15 in 1968. Assuming a 10-year productive life, a few liquid mix plants may already be obsolete, worn out, or closed; most probably have productive life remaining. Although they cannot economically compete with dry blend plants on a cost basis, liquid mix plants may be able to maintain a market through nonprice competition. The handling characteristics of liquids give them some advantages over dry products. Although labor costs associated with each were considered in this study, each involves different types of labor. If a farmer must handle dry products by hand, the labor requirements are physically demanding. With liquids, the labor involved is primarily surveillance, requiring little physical effort. Aggressive marketing that concentrates on this characteristic of liquids, along with other persuasive messages, may generate advantages not based on costs and allow clear-liquid mixers to operate profitably. But unless reductions in the cost of supplying liquid mixes can be achieved, these mixers can expect stiff competition from lower cost blended fertilizers.

As the less efficient mixing facilities that currently exist are supplanted by large-scale bulk blenders, performance in this section of the fertilizer industry should improve considerably. The specialization resulting from the prevalence of one basic type of mixing facility should allow perfection of the blending process, quality improvement, waste reduction, and further cost minimization. However, the relatively large throughput necessary for cost minimization requires improved marketing and distribution programs. Only through a higher degree of management sophistication can the economic advantages be realized. The opportunity and ability of larger corporations

and supply cooperatives to select and train the type of managers necessary to operate the blending operations successfully may give these larger firms an advantage over independent businessmen. In addition, the size of investments required by the larger plants will tend to reduce the ease with which independent businessmen have traditionally entered the fertilizer industry.

Retail Outlets

In the longrun optimal organization of the fertilizer industry, all products used on farms would bypass retail outlets. Though anhydrous ammonia would be trucked directly to farms from the production facilities, the blended product moves to the farm directly or through a satellite outlet. This organization of the industry has important implications for retailers.

In the longrun scheme, blending firms would retail their products much as they currently do. However, the intensity of their retailing effort would change somewhat. These firms would aim at a much larger market area and their facilities would be used at higher levels. Thus, an improved sales program would be necessary, and management would have to improve its organization and operations, particularly the coordination of the distribution system.

Dry retailers, other than bulk blenders, have a rather bleak future in the short as well as long run because they are not economically competitive with alternative distribution systems. Therefore, their continual existence must depend on considerations other than economic efficiency. (By developing a highly marketable service program, for example, retailers may be able to survive for some time.) Many of the approximately 530 dry retail outlets have limited alternative uses for their facilities. However, a few could serve as satellite outlets for the blending operations. Their sole use would be to break down large shipments from the blender into smaller loads for farm delivery.

Some of the better managers may be able to use their skills working for the bulk blenders. Since these firms would sell and distribute directly to farmers, they would have to bolster their staff, thus creating opportunities for managers of local retail outlets.

The ammonia retailers' future is not quite as bleak. Although they are suboptimal in the long run, they can distribute economically in the short run. When anhydrous ammonia is transported from the Gulf Coast to Michigan, costs are minimized if the ammonia moves by rail to retailers for farm distribution. But in the long run, producing ammonia is cheaper in Michigan, and the retailer is not the cheapest distribution route. Current ammonia production capacity in Michigan is not great. Thus, many retail outlets would be useful until production capacity is increased, at which time, the better managers and retailers might have some employment opportunities with the basic ammonia producer.

IMPLICATIONS FOR FARMERS

The performance of the fertilizer industry is not a new topic. In the past, fertilizer suppliers have asserted that they produce only what farmers are willing to buy, that demand for suboptimal products forces their production, and that lack of demand for superior products has prevented their production. On the other hand, farmers have argued that they often purchased suboptimal products because they had no alternatives, or that promotional efforts have persuaded them to be satisfied with suboptimal or high-cost products.

Regardless of the validity of past arguments, farmers today hold sufficient power in the fertilizer market to communicate their desires clearly, such power arises partly from over investment in production and distribution capability in the industry, which has sent suppliers into a concerted search for customers. As a result, in a market characterized by keen price competition, farmers can influence, if not directly, trends and developments in the industry.

Thus, if the industry is to reorganize, farmers must make substantial changes in their buying behavior and consumption patterns. They are the key to the reorganization of the fertilizer industry. Farmers could choose to continue to consume inferior products in a suboptimal market; such a choice would greatly retard the ability of the industry to improve performance. Or, by changing their purchases and consumption, farmers could bring on the numerous adjustments necessary to realize a possible reduction of one-third in the cost of supplying their nutrient requirements.

Realization of potential savings may well require significant changes in farmers' values and beliefs. Or, alternatively, maintaining certain existing values involves associated costs, which could be quite substantial. Although the optimal organization could result in substantial savings, the shifts in beliefs and values require to realize such savings may be too difficult. The following discussion provides insight into the values involved by analyzing implications of the study's findings for farmers.

Minimum cost of providing fertilizer nutrients to farmers was determined. It was assumed throughout that Michigan farmers want to minimize costs of nutrients they use and that they know how to do so. But have they done so?

A review of dry mixed fertilizers consumed in Michigan in 1970 provides relevant information (table 8). Seven mixes contained 20 percent or less nutrient material, accounting for approximately 12,000 tons of product. Thirty-two had nutrient content less than or equal to 40 percent and represented 125,000 tons. By modern standards, any item with 40 percent nutrient material or less can be considered a low-analysis product. The fertilizer consumed in Michigan in 1970 carried an average analysis of 50 percent. Although up somewhat from the 1965 level of 43 percent, this share was well below the attainable level of 66 percent nutrient material.

Assuming that fertilizer nutrients are more expensive in low-analysis than in high-analysis products, one might conclude that farmers do not choose to minimize fertilizer costs. However, several other factors could bring about this situation. First, although farmers may desire to minimize nutrient cost, they may not know which fertilizer materials to use. Second, a farmer may have unique considerations which affect his decision. For example, he could have fixed investment in equipment for applying suboptimal types of fertilizers. Third, fertilizer firms could have pricing policies that do not allow prices of different fertilizer products to reflect relative costs of production and distribution. Therefore, such prices could lead to product choices that would contrast with choices based on production and distribution costs. Additionally, farmers could have certain beliefs and values about some products that narrow their list of considered alternatives. Other beliefs might affect what they perceive to be acceptable alternatives. For example, the safety of anhydrous ammonia or the segregation characteristics of bulk blends could be seen as undesirable, when there is actually little basis for such a belief.

All these factors combine to lead farmers to choices that are less than optimal from the standpoint of cost minimization. If they decide that cost minimization is a primary goal, farmers need to learn to select the appropriate products. Of course, farmers would not be expected to adjust products in the optimum mix unless the price structure adequately reflected cost relationships among alternative choices.

In the long run, monoammonium phosphate and granular potassium chloride in bulk

Table 8.--Dry mixed fertilizer grades sold in Michigan, January 1 through December 31, 1970

Grade	Tons	Grade	Tons
0-10-30	3,131	10-10-20	2,866
0-10-47	166	10-20-10	21,586
0-11-40	263	10-20-20	11,190
0-13-39	410	10-20-30	201
0-14-41	1,462	10-22-14	3,983
0-14-42	3,256	10-26-26	1,398
0-15-30	87	10-40- 8	1,364
0-15-40	651	10-40-10	1,093
0-18-36	604	10-42- 5	227
0-20-20	831	11-44- 9	911
0-25-25	2,895	12- 4- 8	1,584
0-26-26	3,143	12- 6- 6	494
4-16-16	360	12- 6-24	686
5- 8- 7	45	12-12-12	57,090
5-10- 5	517	12-24-12	104
5-10-10	86	12-24-24	2,563
5-10-30	3,535	13-13-13	2,588
5-15-30	228	13-52- 0	3,248
5-20-20	37,505	14- 3- 3	3,248
5-20-30	82	14-14-14	5,508
6-10- 4	291	15-15-15	7,474
6-12-12	304	15-30-15	412
6-18-36	259	16- 4- 8	366
6-24-12	2,759	16- 8- 8	6,846
6-24-24	158,106	16-16-16	41,953
6-26-26	630	17-17-17	5,661
7- 8- 5	22	18-46- 0	6,888
7- 9- 5	82	19-19-19	314
7-28-14	417	20- 5- 5	406
7-28-28	4,266	20-10- 5	2,187
8- 8- 8	101	20-10-10	1,967
8-26-26	2,808	20-20-20	100
8-32- 7	625	21- 0-21	489
8-32-16	82,396	21-53- 0	29
8-36-10	2,735	22- 5- 5	1,710
9-23-30	1,211	22- 6- 6	137
9-36- 6	223	23- 7- 7	2,746
9-36-18	2,157	24- 6- 6	1,473
10-3- 7	73	25- 5-10	372
10-6- 4	10,933	30-10-10	29
10-8- 6	87	Miscellaneous	68,060
10-10-10	3,767	Total	601,854

Source: (20).

blends, along with supplemental anhydrous ammonia for direct application, would minimize costs of providing required plant nutrients. Prices might not always reflect the cost structure properly, however. Additionally, optimal products might not always be available to, or suitable for use by, every farmer in the relevant market area. Therefore, each farmer must evaluate the nutrient cost of alternative fertilizers available to him to assure that he is obtaining the optimal product mix. In some localities, monoammonium phosphate might not be available, and diammonium phosphate would be the best choice. Further, on some crops or under some field conditions, anhydrous ammonia might not be technically useable as a source of supplemental nitrogen. Other products, particularly urea, would become feasible alternatives.

Purchase of optimal products would be a great change from those consumed in 1970. A large number of dry mixed grades accounted for 67 percent of total fertilizer sales in Michigan in 1970 (table 8). Liquid mixes, straight products (dry and liquid), and custom blends were also used (table 9). Of the large number of liquid mixes sold, three accounted for more than 1,000 tons each; most grades accounted for less than 10 tons each. Besides the liquid mixes, approximately 20 products were used as inputs in custom blends (liquid and dry) and together represented less than 4 percent of total fertilizer used.

Direct application of straight products accounted for 25 percent of total fertilizer sales. Of these, anhydrous ammonia was used the most--62,074 tons. Other primary sources of nitrogen included 28 percent nitrogen solution (39,035 tons), ammonium nitrate (24,816 tons), and urea (22,689 tons). Very little phosphate was applied in straight products, and potassium chloride (60 percent and 62 percent) made up nearly all direct application of potash. The remaining 2 percent of fertilizer sales consisted of micronutrients (2,002 tons) and organics and conditioners (15,092 tons). Thus, more than 20 straight products were used on Michigan farms, along with dry and liquid custom blends, and several hundred grades of bulk-blended and granulated fertilizers. This composition contrasts sharply with products that make up the optimal mix.

If farmers are to maximize their inherent power as buyers, implications go beyond their choice of products. A further consideration is their choice of retailers--from whom they buy and receive their products. As previously discussed, costs are minimized when large-scale blenders distribute custom blends both directly and through satellite outlets, and when a central Michigan producer distributes ammonia directly. Thus, bulk blends could be transported to farms from a blender or satellite outlet as far as 20 miles away, while the ammonia could come from a plant up to 100 miles away. This organization contrasts sharply with the current organization in which most fertilizer is distributed through local retailers.

Farmers put forth several reasons for purchasing their fertilizer where they do. Among these are price, discounts, quality, personality of dealer including honesty and reliability, good service, convenience, and brand. Where farmers have selected dealers based on costs, they could easily switch to the more efficient organization since substantial savings would result. But the switch might require sacrificing or altering certain values. For example, buying fertilizer from a dealer 20 miles away would certainly require a farmer's sacrificing his preference for the local dealer (possibly his good friend), and probably his brand loyalty.

Besides product and dealer selection, efforts to minimize costs would affect farmers' consumption patterns. For example, because bulk blenders would serve larger market areas than are served currently, a much improved coordination system would be necessary to keep fertilizer flowing smoothly to farms during the peak season of use. Consequently, the farmer could lose some flexibility as to when the product would be delivered.

Table 9.--Fertilizer sold in Michigan, January 1 through December 31, 1970

Liquid mixed grades	Tons	Liquid nitrogen products	Tons
1-1-1	6	Anhydrous ammonia	62,074
4-10-10	751	Aqueous ammonia (20.5)	4,601
5-10-30	63	Nitrogen solutions:	
6-18-6	1,320	28 percent	39,035
8-25-3	973	32 percent	672
10-10-10	69	37 percent	2,155
10-20-10	2,780	Total	108,537
10-34-0	2,380		
12-6-6	47	Dry mixed grades	1/601,854
13-13-13	229		
Miscellaneous	10,465		
Total	19,083		

Fertilizer material	Direct application	Custom blend
	Tons	
Ammonium nitrate	24,816	2,619
Ammonium sulfate	1,825	541
Urea	22,689	1,091
Nitrate of soda	320	50
Superphosphate (20 percent)	356	1,184
Superphosphate (46 percent)	3,464	2,954
Sulfate of potash	1,957	376
Potassium chloride (60 percent)	55,266	18,046
Potassium chloride (62 percent)	3,289	543
Sulfate of potash magnesia	476	229
Diammonium phosphate (18-46-0)		6,347
Ammonium polyphosphate (10-34-0)	0	111
Ammonium polyphosphate (13-52-0)	0	37
Superphosphate (42 percent)	0	274
Aqueous ammonia	0	76
Phosphoric acid	0	37
Bonemeal	312	0
Calcium nitrate	457	0
Rock phosphate	277	0
Nitrate of soda potash	100	0
Ureaform	143	0
Miscellaneous	28	39
Total	115,775	34,558

1/ Table 8.

Source: (20).

Exclusive use of anhydrous ammonia as a source of supplemental nitrogen also requires certain changes in fertilization practices. Since it is a high-pressure gas, ammonia must be injected into the soil several inches deep to prevent product loss. Although it can be applied during plowing or with a knife-in applicator before planting, ammonia can be used after planting only on row crops and not on cover crops such as wheat or grasses without doing considerable damage to the crop. If it is to be used on cover crops, ammonia must be applied before planting. Suboptimal nitrogen products must be used for postplant applications.

Thus, if farmers and fertilizer suppliers reorganize their activities to achieve the potential savings, farmers would have to change their purchase and consumption patterns significantly and, in all probability, some of their beliefs or values. Farmers may choose not to change, but should recognize the resulting costs.

Farmers' decisionmaking processes can be simplified somewhat in the long run, primarily because the optimal products and distribution facilities are fairly well defined. In the short run, however, the process should not be greatly affected.

Determining how much of which fertilizer to purchase is a more inclusive task than studying the price of various fertilizers. The farmer must also examine production factors that are relevant to fertilizer requirements; such as, the crop to be grown, past cropping, yield goal, soil type, and available plant nutrients. If a farmer fully knows his farm, he may know what yields to expect from various levels of fertilizer use. If he is less sure, he can consult his State experiment station's bulletin on fertilizer recommendations.

By analyzing the relevant factors, the farmer should be able to identify the most profitable fertilization level. Increasing the level pays off as long as additional amounts of fertilizer add less to costs than the resulting increase in the level of crop production adds to total revenue. However, at some higher level, the increase in revenue will no longer exceed the rise in cost, and no more fertilizer should be added.

Before the farmer can make a marginal analysis, he must know the cost of the fertilizer. If he chooses to manage and operate his farm with the goal of profit maximization, he should purchase the fertilizer based on its cost per nutrient content. That is, when buying a nutrient, he should evaluate alternative products based on a unit of that nutrient. Thus, if purchasing N, the farmer should evaluate the cost of each product (purchase price plus transportation and application costs) based on a unit of N. For example, assume the following prices:

Product	Price
	Dollars/ton
Anhydrous ammonia (82 percent)	95
Urea (45 percent)	65
Ammonium nitrate (33.5 percent)	65
Monoammonium phosphate (13-52-0)	82
Triple superphosphate (46 percent)	65
Normal superphosphate (20 percent)	60

To simplify this example, transportation and application costs are omitted. By dividing the cost of each product by its nutrient content, the price of 1 ton of the nutrient supplied through that product is determined: $\frac{\$95}{0.82} = \$115.85$,

$\frac{\$65}{0.45} = \$144.44$, $\frac{\$65}{0.335} = \$194.03$, $\frac{\$65}{0.46} = \$141.30$, and $\frac{\$60}{20} = \$300.00$.

A ton of N in the form of anhydrous ammonia would cost $115.85; in the form of urea, $144.44; and in the form of ammonium nitrate, $194.03. Similarly, a ton of P_2O_5 would cost $141.30 in the form of triple superphosphate and $300.00 in the form of normal superphosphate. The farmer would be well advised to purchase anhydrous ammonia and triple superphosphate to supply N and P_2O_5.

Not all such analysis is this simple, however. Whereas products in the example carry only one nutrient, several straight products and all blended items carry more than one. For example, the monoammonium phosphate listed above carries 13 percent N and 52 percent P_2O_5. The problem is to determine what portion of the price ($82) should be attributed to each of the two nutrients. One approach is to allocate to the nitrogen component the portion of total price that would make the nitrogen cost the same as it costs in its cheapest alternative source, which is ammonia. In this form, the nitrogen costs $115.85 a ton. The monoammonium phosphate is 13 percent N; 13 percent of $115.85 is $15.06, which is the portion of the total price of $82 that can be attributed to nitrogen. Thus, the nitrogen costs exactly the same as it would in anhydrous ammonia, the cheapest alternative source. The remainder--$66.94 ($82 minus $15.06)--would be attributed to the P_2O_5 in the monoammonium phosphate. Since the phosphate contains 52 percent P_2O_5, a ton of phosphate supplied in this product costs $128.73. Thus, the P_2O_5 in monoammonium phosphate is cheaper than in alternative sources, when nitrogen in the product is priced at its cheapest alternative source.

The analysis could as easily have been reversed, pricing the P_2O_5 at its cheapest alternative source and determining the value of nitrogen in the product. Since triple superphosphate is the cheapest source at $141.30 per ton of P_2O_5, the value of P_2O_5 in the monoammonium phosphate can be calculated at $73.48 (141.30 times 0.52). The figure for the N is $8.52, which comes to $65.54 per ton of N. Therefore, the N in monoammonium phosphate is cheaper than in alternative sources, when the P_2O_5 in the product is priced at its cheapest alternative source.

Thus, either way the analysis is conducted, monoammonium phosphate is a desirable product. The farmer should use it until his N or P_2O_5 requirement is satisfied. If his P_2O_5 requirement is satisfied first, which is the most likely, he should supplement with anhydrous ammonia. If, however, his N requirement is satisfied first, he should supplement with triple superphosphate.

Although this analysis was relatively straightforward, a complete evaluation may take a considerable amount of time when more products are added to the list. And if products containing all three nutrients are available, the task may well become overwhelming. In the latter case, if the product carrying the three nutrients is a blend, the farmer may ask for a price list of the inputs. Since each input would carry no more than two nutrients, the analysis would be simplified somewhat. However, a blending charge would have to be added to the individual inputs so that the cost of the final blended product would be reflected accurately by the cost of each input.

Transition to optimal organization of the industry would require resource adjustment at the farm level. A number of farmers are equipped to handle liquid products, including liquid mixes and straight nitrogen products. Since these products have an economic disadvantage, farmers may choose to disinvest in such equipment. However, a decision to salvage expensive equipment and switch to a product with less desirable handling characteristics would be difficult to make. Such a decision might best be put

off unitl existing equipment has been well depreciated.

Similarly, the amount of dry materials applied would fall from approximately 750,000 tons, the 1970 level, to less than 530,000 tons annually. Fewer applicators would be needed in optimal organization. Since dry applicators tend to have short lives, a reduced rate of replacement as existing applicators become fully depreciated should be a satisfactory method of lowering the number of applicators without bringing additional costs.

A significant increase in ammonia application equipment would be needed to accommodate the projected 100-percent increase in ammonia consumption. While much of this need could be satisfied by custom application and machine rental systems, an increasing number of applicators will probably be owned by farmers.

In conclusion, farmers will apparently have to make substantial changes to realize potential savings from reorganization of the industry. And the gains from lower fertilizer cost may have associated costs in terms of altered beliefs and values. Farmers must evaluate the tradeoff.

A remaining question involves how farmers will get the information necessary for improved decisions. The cooperative extension service has the responsibility of disseminating useful information to farmers and could certainly be an important source. Besides providing information, extension employees could train farmers to make the necessary analysis.

Farmer cooperatives could also serve their clients by demonstrating the efficient choice of fertilizers and by marketing products that provide nutrients at as low a cost as possible. Cooperatives would not only be aiding their clients but also improving their competitive advantage and market position. Similarly, fertilizer companies could engage in educational programs to foster an understanding of the economics of alternative products and distribution systems. In any event, illustrating the dollar savings should be sufficient to induce farmers to adjust their purchase and use patterns.

IMPLICATIONS FOR RELATED INDUSTRIES

The Sulfur Industry

In the past 3 years, the price of sulfur has fallen dramatically. The current price of nearly $7 per long ton compared with the 1969 high of $35 per long ton. Despite a steadily growing demand, the supply of sulfur has grown at a rate sufficient to bring about this substantial price decline.

Consumption

U.S. sulfur consumption in 1970 was 9,132,000 long tons. Of this amount, over 85 percent was converted to sulfuric acid. The fertilizer industry is the primary user of sulfur and its use has gone up sharply (table 10). Since sulfuric acid is used to produce many high-analysis fertilizers, the continuing trend to these products may increase the demand for sulfur further. In addition, the increasing attention being directed toward using sulfur as a fertilizer nutrient itself may also strengthen its role in the fertilizer industry. Since all remaining sulfur is used in other processing and manufacturing industries, sulfur demand is largely derived, depending on demand for the end products of the industries that use sulfur directly or indirectly as sulfuric acid.

A simple method of projecting aggregate sulfur demand is to assume that it will continue to grow at about the same rate as industrial production. 18/ A longrun annual growth rate of 6.5 percent in industrial production--the rate actually experienced during 1960-69--would imply a rise in annual sulfur consumption from 9,132,000 long tons in 1970 to 12,000,000 long tons in 1975 and 15,100,000 long tons in 1980.

Table 10.--Domestic sulfur consumption, 1966

Consuming sector	Percentage of total sulfur consumption
	Percent
Acid uses:	
Fertilizers	48
Chemicals	18
TiO_2 and other inorganic pigments	6
Iron and steel	3
Rayon and film	3
Petroleum	2
Others	7
Total	87
Nonacid uses:	
Pulp and paper	5
Carbon bisulfide	3
Ground and refined	2
Others	3
Total	13

Source: (13).

Production

In 1970, 9,549,000 long tons of sulfur were produced in the United States. Of this amount, 7,082,000 long tons were Frasch sulfur. This type is simply elemental sulfur mined by the Frasch process and does not differ from elemental sulfur obtained in other ways. Although sulfur is abundant in the earth's crust, only highly concentrated deposits, or domes, located along the Gulf Coast are mined commercially in the United States.

Significant quantities are also recovered from sour natural or refinery gases, which contain hydrogen sulfide. The sulfide is separated from the other gases and converted to sulfur dioxide, which can readily be converted to elemental sulfur (5, p. 329). Besides these two sources, lesser amounts of sulfur are produced as byproduct sulfuric acid and other sulfur compounds by numerous American industries.

18/ However, extreme variations in use of sulfur in the fertilizer industry would have an important effect.

Production of Frasch sulfur in the United States is concentrated in only four firms; the two largest produce 90 percent of the output. Entry into production is effectively barred, but these four firms do not enjoy a high degree of monopoly power. Producers of recovered sulfur and byproduct sulfuric acid have combined with importers to increase considerably the number of suppliers and the supply of sulfur. Amounts of byproduct sulfuric acid are certain to increase considerably when smelters and others are required to recover the sulfur they currently emit as sulfur dioxide. Metal sulfides--such as iron-bearing pyrites and various nonferrous ores that are smelted or refined for their cooper, lead, and zinc content--could be an important source. Reserves of sulfur in these ores in the United States are estimated at 100 million to 150 million tons (1, p. 909).

Large amounts of sulfur can also be extracted from natural gas and crude petroleum. The sulfur content of natural gas in the United States averages about 0.05 percent by weight. The sulfur occurs as hydrogen sulfide in concentrations from zero to 70 percent. The Nation's crude oils contain an average sulfur content of 0.6 percent, and oil shale has 0.75 percent. Sulfur reserves in these three sources are estimated at 105 million tons (28, pp. 29-30). In addition, huge amounts may also exist in the natural gas and petroleum located on the northern slope of Alaska. However, the greatest source of U.S. sulfur lies in coal deposits. Sulfur accounts for an average 2.6 percent of the weight of coal. The sulfur content of recoverable coal reserves in the United States, taken at a conservative 220 billion tons, would come to 5 billion tons or more (1, p. 909).

The domestic market for sulfur is sensitive to international trade. Large amounts are produced in Canada and Mexico and can flow freely to the U.S. market (there is no tariff on sulfur). Whereas Mexico has several high-quality deposits that are up to 95 percent sulfur, most of Canada's sulfur is currently being recovered from natural gas. The Province of Alberta's natural gas contains from 1 to 38 percent hydrogen sulfide, and reserves of sulfur in this source are estimated at 350 million tons. Further amounts of sulfur are being recovered from tar sands in Alberta, the potential reserves have been calculated at 780 million tons (28, p. 29-30).

The increases in domestic production of sulfur, coupled with the U.S. shift from net exporter to net importer, has resulted in substantially increased supplies and a severe decline in price.

Byproduct Sulfur in Michigan

Based on study results, it does not appear economically feasible to use Michigan's potential byproduct sulfur in the fertilizer industry. However, as noted earlier, approximately half the Nation's sulfur is consumed in the fertilizer industry; the other half is used in a great variety of manufacturing industries (table 10), many of which have producers in Michigan. For example, in 1967, there were 36 Michigan firms producing textiles, 214 in paper products, 431 in chemicals, 296 in rubber and plastic 32 in leather and leather products, and 556 in metal products (18, p. 252). All these products use sulfuric acid. The concentrations of sulfur-consuming industries in the North and sulfur supplies primarily in the South result in a superb opportunity for Michigan powerplants that choose to produce sulfuric acid. Its price in Michigan reflects the cost of transporting sulfur into the State and is, therefore, considerably higher than on the Gulf Coast.

The future holds little promise for higher prices in competitive sulfur markets. The potential supply of sulfur will continue to exceed consumption by considerable margins, particularly if production of recovered and byproduct sulfur increases rapidly with the establishment of effective sulfur oxide emission controls. Whether or not recovery of sulfur oxides from flue gas proves economical, the potential supply of by-

product sulfur will continue to rise because removal of the sulfur from fuels is essential. If removal cannot be accomplished by scrubbing flue gas, it will be achieved by fuel desulfurization or some other process. The relevant question is whether the sulfur will be recovered in a useful form. Though the question is not easily answered, there is sound reason to believe that much of the sulfur can be recovered and used. The resulting low prices will encourage its use in producing phosphoric acid for fertilizer, as well as in other industries. (The role of electricity and elemental phosphorus will depend on the suboptimal use of phosphoric acid in the Midwest and North and in nonfertilizer uses.)

Firms producing Frasch sulfur can expect keen competition from byproduct sulfur. They can enhance their economic position by working mines in which costs are at a minimum and by directing their marketing efforts to the nearby phosphate producers and other users. Northern industrial firms that need large amounts of sulfuric acid have an incentive to push for sulfur oxide abatement, because the price of sulfuric acid would be expected to fall.

The Power Industry

Society is becoming increasingly concerned with the detrimental effects of air pollution. For example, public opinion surveys indicate that dirty air is second only to poor public schools as a factor which drives young middle-income people from urban centers (6, p. 552). One of the most costly pollutants, sulfur oxides attack both plant and animal life. Incidents have been recorded where vegetation 50 miles from the source of sulfur oxide emissions has been injured (27, p. 15). Humans have been victimized individually as well as collectively. Sulfur oxides attack materials too; few metals, stones, or fabrics are exempt. Laws controlling sulfur oxide emissions have been established in some urban areas, and more legislation is sure to follow.

The combustion of fossil fuels accounts for 85 percent of all sulfur oxides emitted into the atmosphere, with coal representing 60 percent of this amount. 19/ Electric powerplants put out over half of all sulfur oxide emissions (24, p. 187). The 274 million tons of coal burned yearly by electric powerplants produce 13 million tons of sulfur oxide; the 156 million barrels of oil used annually account for 1 million tons; and 2,739 billion cubic feet of gas burned each year represent 3,500 tons of sulfur oxides.

To provide further perspective, a comparison can be made of the sulfur coming from electric power-generating plants with the output of the sulfur industry. Powerplants were estimated as emitting 10 million tons of sulfur in oxides during 1970 (8). Sulfur consumption for all purposes in the United States was only 11 million tons in that year. The sulfur emitted from powerplants in 1970 was equivalent to 30.7 million tons of sulfuric acid, which slightly exceeds the 30.6 million tons of sulfuric acid produced by the domestic sulfur industry in 1970. The U.S. fertilizer industry, the primary consumer of sulfuric acid, used about 50 percent of the potential sulfuric acid production from power plants.

Several alternatives are available for controlling sulfur oxide emissions, and most of them will probably be used. Construction of smokestacks 500 to 1,000 feet tall and locating powerplants away from urban centers reduces the concentration of sulfur oxides in heavily populated areas, but does not cut down on total sulfur oxide emissions. Use of low sulfur fuels during pollution alerts will be strategic, but their limited supply makes continual use impossible on a regional or national scale for an extended

19/ (25). Other sources include refinery operations, smelting of ores, coke processing, sulfuric acid manufacturing, coal refuse banks, and refuse incineration.

period. Mass desulfurization of oil will become an important source of low-sulfur fuel in the near future.

Unless great technological advances are made in desulfurizing coal, the process will not be commonly employed. Instead, use of smokestack scrubbers to remove sulfur oxides from flue gas will be the method of coal-burning powerplants. Constraints on construction of atomic powerplants prevents their widespread substitution for coal-burning plants, and coal will continue to be a primary power source for some time to come. Consequently, sulfur oxide recovery systems will become a standard component of nearly all newly constructed coal-burning powerplants. Many of the existing larger plants may also be equipped with scrubber systems, but equipping smaller or older coal-burning powerplants would probably not be feasible.

Although sulfur oxide control equipment will require considerable investment, regulators have been encouraging power firms to make such investments by allowing the expenditures as bona fide costs of producing electricity. Regulators perceive that society is seriously concerned about the damages caused by effluents from electric power generation, and wants abatement measures. One method of meeting the resulting cost would be in the form of higher electrical rates.

Currently, few power firms have installed abatement equipment, probably because of the risk involved in using an essentially unproved system. Engineers at the TVA Development Center believe that such basic problems as corrosion and plugging have not been sufficiently solved. Power firms may also be discouraged from investing in abatement equipment because of the impact higher electrical rates could have on the quantity of electricity demanded, particularly by industrial users.

Power firms will be able to choose from a number of processes once these have been sufficiently refined. Each process currently being developed will produce a byproduct (to the product, clean air) which will fall in one of three possible classes: a product not currently marketable, such as calcium sulfate; ammonium sulfate, usable as a fertilizer; or sulfur or sulfuric acid, chemicals used in many industries.

This study indicates that a power firm in Michigan can expect to generate considerably more revenue from producing sulfuric acid than from producing ammonium sulfate. At the current price of $31.60 per ton for sulfuric acid, returns to the power firm can be substantial. For example, if the board of water and light in Lansing recovered 90 percent of its sulfur as sulfuric acid and sold it at that price, the publicly owned electric power-generating plant would receive gross revenues of over $2 million annually. The plant's net income was $5,228,664 in 1968 (6, p. 26). If the powerplant marketed the sulfuric acid, however, prices would probably decline but substantial revenue could be generated.

The location of the power firm in relation to the byproduct market area is an important consideration. Since ammonium sulfate is a low-analysis product, it cannot be transported far without loss of its competitive advantage. Therefore, in marketing ammonium sulfate, a power firm in an agricultural area will have a locational advantage over other power firms. On the other hand, for sulfuric acid production, power firms located in industrial areas will have a locational edge on other power firms since the acid is used as an input in manufacturing.

If a powerplant chooses to produce a salable product, it must be prepared to develop a marketing program. Marketing sulfuric acid or ammonium sulfate could be a significant problem for the firm since the marketing characteristics differ considerably from those for electricity. In addition, for years, researchers, extension specialists, and industry personnel have rightfully been informing the farmer that high-analysis fertilizers have the potential for lowest cost per nutrient content. Their efforts at informing farmers have been at least moderately successful and consumption of low-analysis

fertilizers has declined. However, a new situation has arisen in which ammonium sulfate can be a cheap source of nitrogen. Thus marketing efforts will have to include an effective information system. Preference for high-analysis fertilizers could prove to be an important market barrier to powerplants that plan to market byproduct ammonium sulfate.

On the other hand, in analyzing the competitive position of ammonium sulfate, sulfur was assumed to have no fertilizer value. However, some agronomists believe sulfur is an important nutrient, and responses to sulfur-containing fertilizers have been recorded in Michigan (2). If sulfur is found to be an important nutrient, the fertilizer component of ammonium sulfate would rise to 45 percent from 21 percent (21 percent N plus 24 percent S) and its value in the analysis would be understated.

Apparently, some balance between the processes that produce ammonium sulfate, sulfuric acid, and a waste product will evolve. The markets for both ammonium sulfate and sulfuric acid could not absorb all potential byproducts without substantial price reductions. Firms must determine what processes are technically feasible for their plant and evaluate the opportunities. Few firms will find processes that result in ammonium sulfate desirable; more will prefer those that result in sulfuric acid. If the quantity of these byproducts marketed is sufficient to drive prices down considerably, the remaining firms may prefer to use the processes that produce a waste product, although additional disposal problems not addressed in this study would be created.

APPENDIXES

The appendixes provide cost and product use summaries and detailed product flow information for various situations. In the product flow tables, an item in the "Originating Location" column refers to the location of manufacturing facilities for the product, unless otherwise specified, as in "Michigan Terminal." Whenever "Processors," "Retailers," "Satellite Outlets," or "Farms" appear in this column, they refer to facilities located throughout the Michigan market area.

Similarly, items in the "Terminating Location" column refer to manufacturing facilities that use the product as an input, unless otherwise specified, as with "Michigan Terminal." Again, "Processors," "Retailer," "Satellite Outlets," and "Farms" refer to facilities receiving the product that are located throughout the Michigan market area.

APPENDIX A

Table A-1.--Product use summary for supplying specified levels of N, P_2O_5, and K_2O to Michigan farmers under alternative organizations

Item	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
	Dollars		
Total cost	71,445,667	52,555,247	48,297,763
	Tons per year		
N supplied	141,932	141,932	141,932
P_2O_5 supplied	140,650	140,650	140,650
K_2O supplied	155,441	155,441	155,441
Anhydrous ammonia	164,309	171,894	172,828
Aqueous ammonia	3,897	0	0
Nitric acid	59,832	10,539	0
Ammonium nitrate	78,210	13,777	0
Nonpressure nitrogen solution	40,912	0	0
Low-pressure nitrogen solution	28,171	0	0
Nitrogen manufacturing solution	16,067	19,737	0
Urea	52,006	0	0
Granular ammonium sulfate	35,628	0	0
Elemental phosphorous	4,004	0	0
Furnace phosphoric acid	16,866	0	0
Wet-process phosphoric acid	195,455	236,748	260,565
Superphosphoric acid	207	0	0
Ammonium polyphosphate liquid (10-34-0)	4,832	0	0
Ammonium polyphosphate liquid (11-37-0)	402	0	0
Normal superphosphate	53,791	0	0
Run-of-pile triple superphosphate	138,945	115,303	0
Granular triple superphosphate	26,598	5,274	0
Diammonium phosphate	105,205	77,810	0
Monoammonium phosphate	26,244	99,910	270,576
Rock phosphate	277	0	0
Run-of-mine potassium chloride	111,166	121,462	0
Standard potassium chloride	1,877	0	0
Granular potassium chloride	95,919	137,590	259,032
Coarse potassium chloride	50,000	0	0
Granulated mixed fertilizers	388,555	303,655	0
Bulk-blended fertilizers	203,213	185,535	0
Custom-blended fertilizers	27,785	86,465	529,608
Hot-process clear mixed liquids	11,450	0	0
Cold-process clear mixed liquids	7,633	0	0
Suspension liquids	0	0	0

Table A-2.--Flow of anhydrous ammonia with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
Gulf Coast	Production	Centrifugal	----	73,033	80,308	42,886
Gulf Coast	Production	Piston	----	10,363	0	0
Midwest	Production	Centrifugal	----	46,913	45,175	0
Central Michigan	Production	Centrifugal	----	0	0	129,942
Central Michigan	Production	Piston	----	34,000	46,411	0
Gulf Coast	Mfr's. storage	Cyrogenic	----	13,189	45,540	0
Midwest	Mfr's. storage	Cyrogenic	----	0	7,647	0
Central Michigan	Mfr's. storage	Cyrogenic	----	0	0	54,239
Gulf Coast	Product transfer	Onsite	Gulf Coast producers 1/	50,763	7,448	0
Gulf Coast	Transportation	Barge	Florida producers 2/	19,012	27,320	42,886
Gulf Coast	Transportation	Rail	Retailers	13,622	45,540	0
Midwest	Product transfer	Onsite	Midwestern producers 3/	25,946	8,788	0
Midwest	Transportation	Rail	Processors 4/	2,157	0	0
Midwest	Transportation	Rail	Retailers	18,810	0	0
Midwest	Transportation	Truck	Farms	0	36,387	0
Central Michigan	Product transfer	Onsite	Central Michigan 5/	4,350	0	0
Central Michigan	Transportation	Truck	Retailers	29,642	0	0
Central Michigan	Transportation	Truck	Farms	8	46,411	129,942
Retailers	Transportation	Applicators	Farms	62,074	45,540	0
Farms	Application	----	----	62,082	128,338	129,942

1/ Producers of nitric acid, ammonium nitrate, nitrogen manufacturing solutions, and urea.
2/ Producers of diammonium phosphate and monoammonium phosphate.
3/ Producers of nitric acid, ammonium nitrate, nonpressure and low-pressure nitrogen solutions, nitrogen manufacturing solutions, urea, ammoniated polyphosphates, diammonium phosphate, and monoammonium phosphate.
4/ Producers of aqueous ammonia and granular mixed and liquid mixed fertilizer.
5/ Producers of diammonium phosphate and granular mixed fertilizer.

Table A-3.--Flow of aqueous ammonia with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Processors	Production	Ammonia converter	----	3,897	0	0
Processors	Transportation	Rail	Retailers	3,897	0	0
Retailers	Transportation	Applicator	Farms	3,897	0	0
Farms	Application	----	----	3,897	0	0

Table A-4.--Flow of nitric acid with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Gulf Coast	Production	Medium pressure	----	41,882	7,377	0
Midwest	Production	Medium pressure	----	17,950	3,162	0
Gulf Coast	Product transfer	Onsite	Gulf Coast producers 1/	41,882	7,377	0
Midwest	Product transfer	Onsite	Midwestern producers 1/			

1/ Producers of ammonium nitrate.

Table A-5.--Flow of ammonium nitrate with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Gulf Coast	Production	Neutralization-evaporation	—	54,747	9,644	-0-
Midwest	Production	Neutralization-evaporation	—	23,463	4,133	-0-
Gulf Coast	Mfr's. storage	Bulk	—	4,879	-0-	-0-
Gulf Coast	Product transfer	Onsite	Gulf Coast producers 1/	-0-	9,644	-0-
Gulf Coast	Transportation	Barge	Midwestern producers 2/	20,105	-0-	-0-
Gulf Coast	Transportation	Rail	Central Michigan 3/	1,027	-0-	-0-
Gulf Coast	Transportation	Rail	processors 3/	5,912	-0-	-0-
Gulf Coast	Transportation	Rail	retailers	27,704	-0-	-0-
Midwest	Product transfer	Onsite	Central Michigan 2/	23,463	4,133	-0-
Retailers	Transportation	Applicators	Farms	27,704	-0-	-0-
Farms	Application	—	—	27,704	-0-	-0-

1/ Producers of nitrogen manufacturing solutions.
2/ Producers of nonpressure and low-pressure nitrogen solutions and nitrogen manufacturing solutions.
3/ Producers of granulated mixed and dry blended fertilizer.

Table A-6.--Flow of nonpressure nitrogen solutions with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Midwest	Production	Blending	—	40,912	-0-	-0-
Midwest	Mfr's. storage	Tank	—	40,635	-0-	-0-
Midwest	Transportation	Rail	Processors 1/	1,109	-0-	-0-
Midwest	Transportation	Rail	Retailers	39,803	-0-	-0-
Retailers	Transportation	Applicators	Farms	39,803	-0-	-0-
Farms	Application	—	—	39,803	-0-	-0-

1/ Producers of cold-process liquid mixed fertilizer.

Table A-7.--Flow of low-pressure nitrogen solutions with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				---------------Tons per year	-------------	
Midwest	Production	Blending	—	28,171	-0-	-0-
Midwest	Mfr's. storage	Tank	—	9,472	-0-	-0-
Midwest	Transportation	Rail	Central Michigan 1/	16,260	-0-	-0-
Midwest	Transportation	Rail	Processors 1/	9,756	-0-	-0-
Midwest	Transportation	Rail	Retailers 1/	2,155	-0-	-0-
Retailers	Transportation	Applicators	Farms	2,155	-0-	-0-
Farms	Application	—	—	2,155	-0-	-0-

1/ Producers of granulated mixed fertilizer.

Table A-8.--Flow of nitrogen manufacturing solutions with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				---------------Tons per year	-------------	
Gulf Coast	Production	Blending	—	-0-	13,816	-0-
Midwest	Production	Blending	—	16,067	5,921	-0-
Gulf Coast	Mfr's. storage	Tank	—	-0-	2,616	-0-
Midwest	Mfr's. storage	Tank	—	4,519	-0-	-0-
Gulf Coast	Transportation	Rail	Central Michigan 1/	-0-	10,329	-0-
Gulf Coast	Transportation	Rail	Processors 1/	-0-	3,488	-0-
Midwest	Transportation	Rail	Central Michigan 1/	10,042	5,921	-0-
Midwest	Transportation	Rail	Processors 1/	6,025	-0-	-0-

1/ Producers of granulated mixed fertilizer.

Table A-9.--Flow of urea with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Gulf Coast	Production	Gas separation	—	29,470	-0-	-0-
Gulf Coast	Production	Ammonium carbamate slurry	—	6,934	-0-	-0-
Gulf Coast	Production	Water absorption	—	10,401	-0-	-0-
Midwest	Production	Gas separation	—	5,201	-0-	-0-
Gulf Coast	Mfr's storage	Bulk	—	33,878	-0-	-0-
Gulf Coast	Transportation	Barge	Midwestern producers 1/	9,651	-0-	-0-
Gulf Coast	Transportation	Rail	Central Michigan 2/	1,247	-0-	-0-
Gulf Coast	Transportation	Rail	Processors 2/	11,861	-0-	-0-
Gulf Coast	Transportation	Rail	Retailers	24,047	-0-	-0-
Midwest	Product transfer	Onsite	Midwestern producers 1/	5,201	-0-	-0-
Retailers	Transportation	Applicators	Farms	24,047	-0-	-0-
Farms	Application	—	—	24,047	-0-	-0-

1/ Producers of nonpressure nitrogen solutions.
2/ Producers of granulated mixed and dry blended fertilizer.

Table A-10.--Flow of ammonium sulfate with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Central Michigan	Purchase	—	—	11,174	-0-	-0-
Processors	Purchase	—	—	21,984	-0-	-0-
Retailers	Purchase	—	—	2,470	-0-	-0-
Retailiers	Transportation	Applicators	Farms	2,470	-0-	-0-
Farms	Application	—	—	2,470	-0-	-0-

Table A-11.--Flow of elemental phosphorus with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Florida	Production	Electric furnace	—	4,004	-0-	-0-
Florida	Transportation	Barge	Midwestern producers 1/	27	-0-	-0-
Florida	Transportation	Rail	Central Michigan 1/	3,977	-0-	-0-

1/ Producers of furnace phosphoric and superphosphoric acid.

Table A-12.--Flow of furnace phosphoric acid with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Central Michigan	Production	Furnace process	—	16,866	-0-	-0-
Central Michigan	Product transfer	Onsite	Central Michigan 1/	16,866	-0-	-0-

1/ Producers of diammonium phosphate.

Table A-13.--Flow of wet-process phosphoric acid with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Florida	Production	Wet process	—	134,864	163,356	260,565
Midwest	Production	Wet process	—	60,591	73,392	-0-
Florida	Mfr's. storage	Rubber-lined	—	3,561	-0-	-0-
Florida	Product transfer	Onsite	Florida producers 1/	134,864	163,356	260,565
Midwest	Product transfer	Onsite	Midwestern producers 1/	55,843	73,392	-0-
Midwest	Transportation	Rail	Processors 2/	4,748	-0-	-0-

1/ Producers of ammoniated polyphosphates, triple superphosphate, diammonium phosphate, and monoammonium phosphate.
2/ Producers of hot-process clear mixed liquid fertilizer.

Table A-14.--Flow of superphosphoric acid with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				---------------	Tons per year	---------------
Midwest	Production	Thermal	—	207	-0-	- -
Midwest	Product transfer	Onsite	Midwestern producers 1/	207	-0-	-.-

1/ Producers of ammoniated polyphosphates.

Table A-15.--Flow of ammoniated polyphosphate (10-34-0) with alternative industry organization.

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				---------------	Tons per year	---------------
Midwest	Production	Ammoniation	—	4,832	-0-	-0-
Midwest	Mfr's. storage	Tank	—	3,624	-0-	-0-
Midwest	Transportation	Rail	Processors 1/	4,832	-0-	-0-

1/ Producers of cold-process clear mixed liquid fertilizer.

Table A-16.--Flow of ammoniated polyphosphate (11-37-0) with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				---------------	Tons per year	---------------
Midwest	Production	Ammoniation	—	402	-0-	-0-
Midwest	Mfr's. storage	Tank	—	302	-0-	-0-
Midwest	Transportation	Rail	Processors 1/	402	-0-	-0-

1/ Producers of cold-process clear mixed liquid fertilizer.

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				--Tons per year--		
Florida	Production	Cone mixer	----	21,791	0	0
Central Michigan	Production	Cone mixer	----	32,000	0	0
Florida	Mfr's. storage	Bulk	----	16,660	0	0
Florida	Transportation	Rail	Processors1/	21,791	0	0
Central	Product transfer	Onsite	Central Michigan 1/	31,540	0	0
Central Michigan	Transportation	Rail	Processors1/	89	0	0
Central Michigan	Transportation	Rail	Retailers	371	0	0
Retailers	Transportation	Applicators	Farms	371	0	0
Farms	Application	----	----	371	0	0

1/ Producers of granulated mixed and dry blended fertilizer

Table A-18.--Flow of run-of-pile triple superphosphate with alternative industry organization

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				--Tons per year--		
Florida	Production	Cone mixer	----	83,085	44,234	0
Midwest	Production	Cone mixer	----	55,860	71,069	0
Florida	Mfr's. storage	Bulk	----	55,907	25,897	0
Florida	Product transfer	Onsite	Florida producers1/	27,130	5,380	0
Florida	Transportation	Rail	Central Michigan 2/	14,024	38,854	0
Florida	Transportation	Rail	Processors2/	41,930	0	0
Midwest	Transportation	Rail	Central Michigan 2/	55,860	51,646	0
Midwest	Transportation	Rail	Processors2/	0	19,423	0

1/ Producers of granulated triple superphosphate.
2/ Producers of granulated mixed fertilizers.

Table A-19.--Flow of granular triple superphosphate with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Florida	Production	Rotary drum granulator	—	26,598	5,274	-0-
Florida	Mfr's. storage	Bulk	—	17,242	3,956	-0-
Florida	Transportation	Rail	Central Michigan 1/	1,831	-0-	-0-
Florida	Transportation	Rail	Processors 1/	21,159	5,274	-0-
Florida	Transportation	Rail	Retailers 1/	3,608	-0-	-0-
Retailers	Transportation	Applicators	Farms	3,608	-0-	-0-
Farms	Application	—	—	3,608	-0-	-0-

1/ Producers of dry blended fertilizer.

Table A-20.--Flow of diammonium phosphate with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Florida	Production	Slurry ammoniation	—	70,886	64,582	-0-
Midwest	Production	Slurry ammoniation	—	14,519	13,228	-0-
Central Michigan	Production	Slurry ammoniation	—	19,800	-0-	-0-
Florida	Mfr's. storage	Bulk	—	51,194	28,358	-0-
Florida	Transportation	Rail	Central Michigan 1/	-0-	26,772	-0-
Florida	Transportation	Rail	Processors 1/	64,048	37,810	-0-
Florida	Transportation	Rail	Retailers 1/	6,838	-0-	-0-
Midwest	Transportation	Rail	Central Michigan 1/	14,478	13,228	-0-
Midwest	Transportation	Rail	Processors 1/	40	-0-	-0-
Central Michigan	Product transfer	Onsite	Central Michigan 1/	19,800	-0-	-0-
Retailers	Transportation	Applicators	Farms	6,838	-0-	-0-
Farms	Application	—	—	6,838	-0-	-0-

1/ Producers of granulated mixed and dry blended fertilizer.

Table A-21.--Flow of monoammonium phosphate with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Florida	Production	Slurry ammoniation	—	21,783	82,926	270,576
Midwest	Production	Slurry ammoniation	—	4,461	16,985	-0-
Florida	Mfr's. storage	Bulk	—	17,231	74,933	202,932
Florida	Transportation	Rail	Processors 1/	18,514	72,156	270,576
Florida	Transportation	Rail	Retailers	3,269	-0-	-0-
Florida	Transportation	Rail	Central Michigan 1/	-0-	10,770	-0-
Midwest	Transportation	Rail	Central Michigan 1/	2,180	-0-	-0-
Midwest	Transportation	Rail	Processors 1/	2,281	16,985	-0-
Retailers	Transportation	Applicators	Farms	3,269	-0-	-0-
Farms	Application	—	—	3,269	-0-	-0-

1/ Producers of dry blended fertilizer.

Table A-22.--Flow of phosphate rock with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Florida	Production	Grinding	—	277	-0-	-0-
Florida	Transportation	Rail	Retailers	277	-0-	-0-
Retailers	Transportation	Applicators	Farms	277	-0-	-0-
Farms	Application	—	—	277	-0-	-0-

Table A-23.--*Flow of run-of-mine potassium chloride with alternative industry organizations*

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Saskatoon	Production	Flotation	—	111,116	121,462	-0-
Saskatoon	Mfr's. storage	Bulk	—	31,265	16,096	-0-
Saskatoon	Transportation	Rail	Central Michigan 1/	69,479	100,000	-0-
Saskatoon	Transportation	Rail	Processors 1/	41,687	21,462	-0-

1/ Producers of granulated mixed fertilizer.

Table A-24.--Flow of standard potassium chloride with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Saskatoon	Production	Flotation	—	1,877	-0-	-0-
Saskatoon	Mfr's. storage	Bulk	—	1,407	-0-	-0-
Saskatoon	Transportation	Rail	Processors 1/	1,877	-0-	-0-

1/ Producers of hot- and cold-process clear mixed liquid fertilizer.

Table A-25.--Flow of granular potassium chloride with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				--------Tons per year--------		
Saskatoon	Production	Flotation	—	95,919	137,590	259,032
Saskatoon	Mfr's. storage	Bulk	—	62,943	103,192	129,535
Saskatoon	Transportation	Rail	Central Michigan 1/	6,321	9,230	-0-
Saskatoon	Transportation	Rail	Processors 1/	77,602	128,360	259,032
Saskatoon	Transportation	Rail	Retailers	11,996	-0-	-0-
Retailers	Transportation	Applicators	Farms	11,996	-0-	-0-
Farms	Application	—	—	11,996	-0-	-0-

1/ Producers of dry blended fertilizer.

Table A-26.--Flow of coarse potassium chloride with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				--------Tons per year--------		
Saskatoon	Production	Flotation	—	50,000	-0-	-0-
Saskatoon	Transportation	Rail	Retailers	50,000	-0-	-0-
Retailers	Transportation	Applicators	Farms	50,000	-0-	-0-
Farms	Application	—	—	50,000	-0-	-0-

Table A-27.--Flow of bagged granulated mixed fertilizers with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Central Michigan	Production	TVA continuous	—	97,139	-0-	-0-
Processors	Production	TVA (30,000 tons per year)	—	58,283	-0-	-0-
Central Michigan	Mfr's. storage	Bagged	—	36,427	-0-	-0-
Central Michigan	Transportation	Truck	Retailers	97,117	-0-	-0-
Central Michigan	Transportation	Truck	Farms	22	-0-	-0-
Processors	Transportation	Truck	Retailers	58,283	-0-	-0-
Retailers	Transportation	Wagons	Farms	155,400	-0-	-0-
Farms	Application	—	—	155,400	-0-	-0-

Table A-28.--Flow of bulk granulated mixed fertilizer with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				---------------	Tons per year	--------------
Central Michigan	Production	TVA continuous process	—	145,708	250,000	-0-
Processors	Production	TVA continuous process	—	87,425	53,655	-0-
Central Michigan	Mfr's. storage	Bulk	—	-0-	187,500	-0-
Central Michigan	Transportation	Rail	Retailers	145,708	-0-	-0-
Central Michigan	Transportation	Truck	Farms	-0-	250,000	-0-
Processors	Transportation	Truck	Retailers	87,425	-0-	-0-
Processors	Transportation	Truck	Farms	-0-	53,655	-0-
Retailers	Transportation	Applicators	Farms	233,133	-0-	-0-
Farms	Application	—	—	233,133	303,655	-0-

Table A-29.--Flow of bagged blended fertilizer with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				---------------	Tons per year	--------------
Central Michigan	Production	Horizontal with rotary drum	—	16,444	-0-	-0-
Processors	Production	Horizontal (1,000 tons per year)	—	6,986	-0-	-0-
Processors	Production	Horizontal (2,500 tons per year)	—	29,787	-0-	-0-
Central Michigan	Transportation	Truck	Retailers	16,444	-0-	-0-
Processors	Transportation	Wagon	Farms	36,773	-0-	-0-
Retailers	Transportation	Wagon	Farms	16,444	-0-	-0-
Farms	Application	—	—	53,217	-0-	-0-

Table A-30.--Flow of bulk-blended fertilizers with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Central Michigan	Production	Horizontal with rotary drum	—	2,902	20,000	-0-
Processors	Production	Horizontal (9,000 tons per year)	—	-0-	252,000	-0-
Processors	Production	Vertical (9,000 tons per year)	—	-0-	-0-	529,608
Processors	Production	Horizontal (2,500 tons per year)	—	141,653	-0-	-0-
Processors	Production	Horizontal (1,000 tons per year)	—	33,226	-0-	-0-
Central Michigan	Transportation	Rail	Retailers	2,902	-0-	-0-
Central Michigan	Transportation	Truck	Farms	-0-	20,000	-0-
Processors	Transportation	Truck	Satellite outlets	-0-	126,000	264,804
Processors	Transportation	Applicators	Farms	174,879	126,000	264,804
Retailers	Transportation	Applicators	Farms	2,902	-0-	-0-
Satellite outlets	Product handling	—	—	-0-	126,000	264,804
Satellite outlets	Transportation	Applicators	Farms	-0-	126,000	264,804
Farms	Application	—	—	177,781	272,000	529,608

Table A-31.--Flow of clear mixed liquid fertilizer with alternative industry organizations

Originating location	Activity	Type	Terminating location	Current industry organization (1970)	Shortrun minimum-cost organization	Longrun minimum-cost organization
				Tons per year		
Processor	Production	Hot process (3,000 tons per year)	—	11,450	-0-	-0-
Processor	Production	Cold blend (1,000 tons per year)	—	7,633	-0-	-0-
Processors	Transportation	Applicators	Farms	19,083	-0-	-0-
Farms	Application	—	—	19,083	-0-	-0-

APPENDIX B

Table B-1.--Cost and product use summary as nitrogen consumption increases relative to P_2O_5 and K_2O

Item	Nutrient ratio: shortrun minimum cost				
	1-1-1	1.2-1-1	1.4-1-1	1.7-1-1	2-1-1
	Dollars per ton				
N	108.33	108.33	109.25	115.04	115.04
P_2O_5	154.23	154.23	153.97	153.86	153.86
K_2O	102.36	102.36	102.25	102.19	102.19
	Tons per year				
N supplied	146,000	175,200	204,400	248,200	292,000
P_2O_5 supplied	146,000	146,000	146,000	146,000	146,000
K_2O supplied	146,000	146,000	146,000	146,000	146,000
Anhydrous ammonia	176,841	212,364	247,800	282,968	354,456
Nitric acid	10,163	10,163	10,163	10,163	10,163
Ammonium nitrate	13,286	13,286	13,286	13,286	13,286
Nitrogen manufacturing solutions	19,034	19,034	19,034	19,034	19,034
Wet-process phosphoric acid	248,366	248,366	248,366	248,366	248,366
Run-of-pile triple superphosphate	106,285	106,285	106,285	106,285	106,285
Granular triple superphosphate	276	276	276	276	276
Diammonium phosphate	48,381	48,381	48,381	48,381	48,381
Monoammonium phosphate	144,037	144,037	144,037	144,037	144,037
Run-of-mine potassium chloride	117,131	117,131	117,131	117,131	117,131
Granular potassium chloride	126,159	126,159	126,159	126,159	126,159
Graunlated mixed fertilizer	292,827	292,827	292,827	292,827	292,827
Dry bulk blends	267,479	267,479	267,479	267,479	267,479
Custom blends	4,521	4,521	4,521	4,521	4,521

Table B-2.--Flow of anhydrous ammonia as nitrogen consumption increases relative to P_2O_5 and K_2O

Originating location	Activity	Type	Terminating location	Nutrient ratio: Shortrun minimum cost				
				1-1-1	1.2-1-1	1.4-1-1	1.7-1-1	2-1-1
				--Tons per year--				
Gulf Coast	Production	Centrifugal	—	82,619	99,215	115,811	117,708	155,626
Gulf Coast	Production	Piston	—	-0-	-0-	-0-	13,316	27,703
Midwest	Production	Centrifugal	—	46,475	55,811	65,147	83,944	103,127
Central Michigan	Production	Centrifugal	—	-0-	-0-	-0-	-0-	-0-
Central Michigan	Production	Piston	—	47,747	57,338	66,930	68,000	68,000
Gulf Coast	Mfr's storage	Cryogenic	—	47,673	64,269	74,800	105,517	139,619
Midwest	Mfr's storage	Cryogenic	—	7,870	9,035	16,266	12,191	4,732
Central Michigan	Mfr's storage	Cryogenic	—	-0-	-0-	-0-	-0-	-0-
Gulf Coast	Product transfer	Onsite	Gulf Coast producers	7,183	7,183	7,183	7,183	7,183
Gulf Coast	Transportation	Barge	Florida producers	27,763	27,763	27,763	27,763	27,763
Gulf Coast	Transportation	Barge	Midwestern producers	-0-	-0-	6,065	8,765	8,765
Gulf Coast	Transportation	Barge	Midwestern terminal	-0-	-0-	-0-	30,717	64,819
Gulf Coast	Transportation	Rail	Retailers	47,673	64,269	74,800	74,800	74,800
Midwest	Product transfer	Onsite	Midwestern producers	8,765	8,765	2,700	-0-	-0-
Midwest	Transportation	Truck	Farms	37,710	47,046	62,447	83,944	103,127
Midwest	Terminaling	—	—	-0-	-0-	-0-	30,717	64,819
Midwestern terminals	Transportation	Truck	Farms	-0-	-0-	-0-	30,717	64,819
Central Michigan	Transportation	Truck	Farms	47,747	57,338	66,930	68,000	68,000
Retailers	Transportation	Applicator	Farms	47,673	64,269	74,800	74,800	74,800
Farms	Application	—	—	133,131	168,654	204,177	257,461	310,746

Table C-1.--Cost and product use summary as potash consumption increases relative to N and P_2O_5

Item	Nutrient ratio: Shortrun			
	1-1-1	1-1-1.2	1-1-1.4	1-1-2
	Dollars per ton			
N	108.33	108.33	108.33	108.33
P_2O_5	154.23	154.23	149.09	149.09
K_2O	102.36	102.36	107.67	107.67
	Tons per year			
N supplied	146,000	146,000	146,000	146,000
P_2O_5 supplied	146,000	146,000	146,000	146,000
K_2O supplied	146,000	175,200	204,400	292,000
Anhydrous ammonia	176,841	176,719	176,830	176,830
Nitric acid	10,163	12,433	14,006	14,006
Ammonium nitrate	13,286	16,252	18,308	18,308
Nitrogen manufacturing solutions	19,034	23,284	26,230	26,230
Urea	-0-	-0-	6,015	6,015
Wet-process phosphoric acid	248,366	241,686	239,126	239,126
Run-of-pile triple superphosphate	106,285	140,019	151,915	151,915
Granular triple superphosphate	276	17,752	5,721	5,721
Diammonium phosphate	48,381	113,521	96,266	96,266
Monoammonium phosphate	144,037	56,923	61,571	61,571
Run-of-mine potassium chloride	117,131	143,284	161,413	161,413
Granular potassium chloride	126,159	148,726	179,329	325,329
Granulated mixed fertilizer	292,827	358,210	402,532	402,532
Dry bulk blends	267,479	105,706	-0-	-0-
Custom blends	4,521	166,294	272,000	272,000

Table D-1.--Cost and product use summary as phosphate consumption increases relative to N and K_2O

Item	Nutrient ratio: Shortrun minimum cost					
	1-1-1	1-1.1-1	1-1.2-1	1-1.4-1	1-1.7-1	1-2-1
	Dollars per ton					
N	108.33	108.33	108.33	108.33	108.33	108.33
P_2O_5	154.23	157.65	158.39	158.55	158.55	163.44
K_2O	102.36	98.94	98.20	98.27	98.27	103.37
	Tons per year					
N supplied	146,000	146,000	146,000	146,000	146,000	146,000
P_2O_5 supplied	146,000	160,600	175,200	204,000	248,200	292,000
K_2O supplied	146,000	146,000	146,000	146,000	146,000	146,000
Anhydrous ammonia	176,841	176,848	176,841	176,730	176,575	177,246
Nitric acid	10,163	10,218	10,479	12,547	15,651	11,013
Ammonium nitrate	13,286	13,357	13,697	16,403	20,460	14,396
Nitrogen manufacturing solutions	19,034	19,136	19,624	23,499	29,312	20,625
Elemental phosphorus	-0-	3,977	3,977	3,977	3,977	3,977
Furnace phosphoric acid	-0-	16,866	16,866	16,866	16,866	16,866
Wet-process phosphoric acid	248,366	258,125	284,950	334,690	409,097	490,082
Run-of-pile triple superphosphate	106,285	106,577	109,289	130,871	163,243	163,875
Granular triple superphosphate	276	-0-	-0-	-0-	-0-	-0-
Diammonium phosphate	48,381	66,903	68,105	77,643	91,952	189,228
Monoammonium phosphate	144,037	155,464	180,084	208,782	251,828	249,459
Run-of-mine potassium chloride	117,131	117,760	120,762	144,609	180,479	166,625
Granular potassium chloride	126,159	125,528	122,530	98,711	62,983	76,684
Granulated mixed fertilizer	292,827	294,440	301,905	361,522	450,948	500,000
Dry bulk blends	267,479	272,000	261,311	176,396	49,024	90,296
Custom blends	4,521	-0-	10,689	95,604	222,976	193,438

Table D-2.--Flow of anhydrous ammonia as phosphate consumption increases relative to N and K_2O

Originating location	Activity	Type	Terminating location	Nutrient ratio: Shortrun minimum cost					
				1-1-1	1-1.1-1	1-1.2-1	1-1.4-1	1-1.7-1	1-2-1
				Tons per year					
Gulf Coast	Production	Centrifugal	—	82,619	82,622	82,619	82,567	82,490	82,808
Midwest	Production	Centrifugal	—	46,475	46,477	46,475	46,446	46,402	46,581
Central Michigan	Production	Centrifugal	—	-0-	-0-	-0-	-0-	-0-	-0-
Central Michigan	Production	Piston	—	47,747	47,749	47,747	47,717	47,673	47,857
Gulf Coast	Mfr's. storage	Cyrogenic	—	47,673	42,021	38,376	31,349	20,808	6,994
Midwest	Mfr's. storage	Cyrogenic	—	7,870	13,402	16,298	17,378	18,997	25,286
Central Michigan	Mfr's. storage	Cyrogenic	—	-0-	-0-	-0-	-0-	-0-	-0-
Gulf Coast	Product transfer	Onsite	Gulf Coast producers	7,183	7,221	7,405	8,868	11,061	7,783
Gulf Coast	Transportation	Barge	Florida producers	27,763	29,034	32,491	38,005	46,274	63,685
Gulf Coast	Transportation	Rail	Retailers	47,673	42,021	38,376	31,379	20,808	6,994
Midwest	Product transfer	Onsite	Midwestern producers	8,765	9,042	9,829	11,585	14,218	16,380
Midwest	Transportation	Truck	Farms	37,710	37,435	36,647	34,862	32,184	30,202
Central Michigan	Transportation	Truck	Farms	47,747	47,749	47,747	47,717	47,673	47,857
Retailers	Transportation	Applicator	Farms	47,673	42,021	38,376	31,349	20,808	6,994
Farms	Application	—	—	133,131	127,206	122,770	112,928	100,665	85,053
Gulf Coast	Transportation	Rail	Michigan producers	-0-	4,346	4,346	4,346	4,346	4,346

Table D-3.--Flow of ammonium nitrate as phosphate consumption increases relative to N and K_2O

Originating location	Activity	Type	Terminating location	Nutrient ratio: Shortrun minimum cost					
				1-1-1	1-1.1-1	1-1.2-1	1-1.4-1	1-1.7-1	1-2-1
				Tons per year					
Gulf Coast	Production	Neutralization evaporation	—	9,300	9,300	9,588	11,482	14,322	10,077
Midwest	Production	Neutralization evaporation	—	3,986	4,007	4,109	4,921	6,138	4,319
Gulf Coast	Product transfer	Onsite	Gulf Coast producers	9,300	9,350	9,588	11,482	14,322	10,077
Midwest	Product transfer	Onsite	Midwestern producers	3,986	4,007	4,109	4,921	6,138	4,319

Table D-4.--Flow of nitrogen manufacturing solution as phosphate consumption increases relative to N and K_2O

Originating location	Activity	Type	Terminating location	Nutrient ratio: Shortrun minimum cost					
				1-1-1	1-1.1-1	1-1.2-1	1-1.4-1	1-1.7-1	1-2-1
				Tons per year					
Gulf Coast	Production	Blending	—	13,324	13,395	13,737	16,449	20,518	14,437
Midwest	Production	Blending	—	5,710	5,741	5,887	7,050	8,794	6,188
Gulf Coast	Mfr's. storage	Tank	—	2,088	2,165	2,530	5,437	9,796	3,281
Gulf Coast	Transportation	Rail	Central Michigan	10,540	10,509	10,363	9,200	7,456	10,062
Gulf Coast	Transportation	Rail	Processors	2,784	2,886	3,374	7,249	13,062	4,375
Midwest	Transportation	Rail	Central Michigan	5,710	5,741	5,887	7,050	8,794	6,188

Table D-5.--Flow of wet-process phosphoric acid as phosphate consumption increases relative to N and K_2O

Originating location	Activity	Type	Terminating location	Nutrient ratio: Shortrun minimum cost					
				1-1-1	1-1.1-1	1-1.2-1	1-1.4-1	1-1.7-1	1-2-1
				Tons per year					
Florida	Production	Wet-process	—	171,372	178,343	196,615	230,880	282,277	338,156
Midwest	Production	Wet-process	—	76,994	80,125	88,335	103,729	126,820	151,926
Florida	Product transfer	Onsite	Florida producers	171,372	178,343	196,615	230,880	282,277	338,156
Midwest	Product transfer	Onsite	Midwestern producers	76,994	80,125	88,335	103,729	126,820	151,926

Table D-6.--Flow of run-of-pile triple superphosphate as phosphate consumption increases relative to N and K_2O

Originating Location	Activity	Type	Terminating location	Nutrient ratio: Shortrun minimum cost					
				1-1-1	1-1.1-1	1-1.2-1	1-1.4-1	1-1.7-1	1-2-1
				Tons per year					
Florida	Production	Cone mixer	—	34,224	32,266	28,764	35,882	46,557	29,476
Midwest	Production	Cone mixer	—	72,061	74,306	80,525	94,989	116,686	134,399
Florida	Mfr's. storage	Bulk	—	20,671	21,430	25,053	35,882	46,557	29,476
Midwest	Mfr's. storage	Bulk	—	-0-	-0-	-0-	17,946	50,434	68,357
Florida	Product transfer	Onsite	Florida producers	281	-0-	-0-	-0-	-0-	-0-
Florida	Transportation	Rail	Central Michigan	33,942	32,266	28,764	35,882	46,557	29,476
Midwest	Transportation	Rail	Central Michigan	56,558	58,234	61,736	54,618	43,943	61,024
Midwest	Transportation	Rail	Processors	15,503	16,073	18,700	40,371	72,743	73,375

Table D-7.--Flow of diammonium phosphate as phosphate consumption increases relative to N and K_2O

Originating location	Activity	Type	Terminating location	Nutrient ratio: Shortrun minimum cost 1-1-1	1-1.1-1	1-1.2-1	1-1.4-1	1-1.7-1	1-2-1
				Tons per year					
Florida	Production	Slurry ammoniation	—	40,156	39,096	40,093	48,010	59,886	140,625
Midwest	Production	Slurry ammoniation	—	8,225	8,007	8,212	9,833	12,266	28,803
Central Michigan	Production	Slurry ammoniation	—	-0-	19,800	19,800	19,800	19,800	19,800
Florida	Mfr's. storage	Bulk	—	6,285	5,328	6,229	13,383	24,114	75,469
Florida	Transportation	Rail	Central Michigan	31,775	31,992	31,788	30,167	27,734	40,000
Florida	Transportation	Rail	Processors	8,380	7,104	8,305	17,844	32,152	100,625
Midwest	Transportation	Rail	Central Michigan	8,225	8,008	8,212	9,833	12,266	-0-
Midwest	Transportation	Truck	Farms	-0-	-0-	-0-	-0-	-0-	28,803
Central Michigan	Transportation	Truck	Farms	-0-	19,800	19,800	19,800	19,800	19,800
Farms	Application	—	—	-0-	19,800	19,800	19,800	19,800	48,603

Table D-8.--Flow of monoammonium phosphate as phosphate consumption increases relative to N and K_2O

Originating location	Activity	Type	Terminating location	Nutrient ratio: Shortrun minimum cost 1-1-1	1-1.1-1	1-1.2-1	1-1.4-1	1-1.7-1	1-2-1
				--Tons per year--					
Florida	Production	Slurry ammoniation	---	119,551	129,035	149,470	173,289	209,017	207,050
Midwest	Production	Slurry ammoniation	---	24,486	26,429	30,614	35,493	42,811	42,409
Florida	Mfr's. storage	Bulk	---	108,028	109,854	112,103	129,967	156,763	155,287
Florida	Transportation	Rail	---	10,770	10,770	10,770	10,770	10,770	10,770
Florida	Transportation	Rail	Processors	108,781	118,265	138,700	162,519	198,247	196,280
Midwest	Transportation	Rail	Processors	24,486	17,437	0	0	0	0
Midwest	Transportation	Truck	Farms	0	8,992	30,614	35,493	42,811	42,409
Farms	Application	---	---	0	8,992	30,614	35,493	42,811	42,409

Table D-9.--Flow of run-of-mine potassium chloride as phosphate consumption increases relative to N and K_2O

Originating location	Activity	Type	Terminating location	Nutrient ratio: Shortrun minimum cost 1-1-1	1-1.1-1	1-1.2-1	1-1.4-1	1-1.7-1	1-2-1
				--Tons per year--					
Saskatoon	Production	Flotation	---	117,131	117,760	120,762	144,609	180,379	166,625
Saskatoon	Mfr's. storage	Bulk	---	12,848	13,320	15,571	33,457	60,284	49,969
Saskatoon	Transportation	Rail	Central Michigan	100,000	100,000	100,000	100,000	100,000	100,000
Saskatoon	Transportation	Rail	Processors	17,131	17,760	20,762	44,609	80,379	66,625

Table D-10.--Flow of granular potassium chloride as phosphate consumption increases relative to N and K_2O

Originating location	Activity	Type	Terminating location	Nutrient ratio: Shortrun minimum cost					
				1-1-1	1-1.1-1	1-1.2-1	1-1.4-1	1-1.7-1	1-2-1
				Tons per year					
Saskatoon	Production	Flotation	—	126,159	125,528	122,530	98,711	62,983	76,684
Saskatoon	Mfr's. storage	Bulk	—	94,619	94,146	91,897	74,033	47,237	57,513
Saskatoon	Transportation	Rail	Central Michigan	9,230	9,230	9,230	9,230	9,230	9,230
Saskatoon	Transportation	Rail	Processors	116,929	116,298	113,300	89,481	53,753	67,454

Table D-11.--Flow of bulk granulated mixed fertilizer as phosphate consumption increases relative to N and K_2O

Originating location	Activity	Type	Terminating location	Nutrient ratio: Shortrun minimum cost					
				1-1-1	1-1.1-1	1-1.2-1	1-1.4-1	1-1.7-1	1-2-1
				Tons per year					
Central Michigan	Production	TVA continuous process	—	250,000	250,000	250,000	250,000	250,000	250,000
Processors	Production	TVA continous process	—	42,827	44,400	51,905	111,522	200,948	250,000
Central Michigan	Mfr's. storage	Bulk	—	187,500	187,500	187,500	187,500	187,500	187,500
Central Michigan	Transportation	Truck	Farms	250,000	250,000	250,000	250,000	250,000	250,000
Processors	Transportation	Truck	Farms	42,827	44,400	51,905	111,522	200,948	250,000
Farms	Application	—	—	292,827	294,400	301,905	361,522	450,948	500,000

Table D-12.--Flow of bulk blended fertilizers as phosphate consumption increases relative to N and K_2O

Originating location	Activity	Type	Terminating location	Nutrient ratio: Shortrun minimum cost					
				1-1-1	1-1.1-1	1-1.2-1	1-1.4-1	1-1.7-1	1-2-1
				Tons per year					
Central Michigan	Production	Horizontal with rotary drum	---	20,000	20,000	20,000	20,000	20,000	20,000
Processors	Production	Horizontal (9,000 tons per year)	---	252,000	252,000	252,000	252,000	252,000	252,000
Processors	Production	Horizontal (2,500 tons per year)	---	0	0	0	0	0	11,734
Central Michigan	Transportation	Truck	Farms	20,000	20,000	20,000	20,000	20,000	20,000
Processors	Transportation	Truck	Satellite outlets	126,000	126,000	126,000	126,000	126,000	131,867
Processors	Transportation	Applicators	Farms	126,000	126,000	126,000	126,000	126,000	131,867
Satellite outlets	Product handling	--	---	126,000	126,000	126,000	126,000	126,000	131,867
Satellite outlets	Transportation	Applicators	Farms	126,000	126,000	126,000	126,000	126,000	131,867
Farms	Application	--	---	272,000	272,000	272,000	272,000	272,000	283,734

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